Cyclic Load Test on Beam-Column Behavior of Portal Frame Strengthening by Micro-Concrete

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A Thesis

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DECLARATION

It is hereby declared that, except where specific references are made, the work embodied in this thesis is the result of investigation carried out by the author under the supervision of Dr. Raquib Ahsan, Professor, Department of Civil Engineering, BUET.

Neither the thesis nor a part of it is concurrently submitted elsewhere for the award of any degree or diploma.

Thesis Supervisor

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DEDICATION

This Thesis is dedicated to our Parents and Teachers

ACKNOWLEDGEMENT

At first, we would like to give thanks to almighty, kindness, merciful, the universal king, Allah who allows us and make us capable to complete this thesis effectively.

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ABSTRACT

In recent years, researches have been increasing towards studying the strengthening of concrete structures using different methods. Various studies have shown that structural concrete members such as reinforced concrete (RC) columns can experience a significant increase in the ultimate load carrying capacity and ductility when strengthened by a concrete jacket. This study aimed at investigating the effectiveness of strengthening the entire height of half-scaled RC columns by applying Micro concrete as a jacketing material. Generally Micro concrete can be found in blended form. But in this study, Micro concrete was produced with the locally available materials. The experimental work included the fabrication of three identical unjacketed reference portal frames having similar geometric dimensions. Each frame consists of a beam (125 mm x 125 mm x 2600 mm), two columns (125 mm x 125 mm x 1250 mm) and a base beam (300 mm x 225 mm x 2400 mm). To investigate the performance of strengthened RC frames the columns of two frames were retrofitted by micro-concrete of 50 mm thickness. To compare the effectiveness of jacketing two different strengths of micro-concrete were used and the variation of strength was introduced by using different grain size and mixing ratio. Each frame was subjected to cyclic incremental horizontal loading with sustained gravity load. The loading and unloading were controlled by horizontal displacement. A comparative study was performed between the Retrofitted Specimens and the control specimen. The retrofitted specimens showed significant increase in the ultimate load carrying capacity about 2.75 times higher than the control specimen. The ultimate load carrying capacity of both retrofitted specimens was same but stiffness of these specimens was different. Though the retrofitted material of first specimen [6.3 ksi] was lower than that of the second specimen [8.16 ksi], the overall stiffness of the first one was higher than the second one. This indicates higher strength of jacketing material doesn’t affect the stiffness and the lateral load carrying capacity significantly and this was because of anchorage failure of the retrofitted columns. The result of the study was compared with the theoretical analysis of the specimens. Comparing the retrofitted specimens with control specimen it was observed that performance of retrofitted specimens were relatively better.

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NOTATIONS

ABBREVIATION

CS	Control Specimen
RS	Retrofitted Specimen
MPa	Mega Pascal
MC	Micro Concrete
ASTM	American Society for Testing and Meterial
RC	Reinforced Concrete
W/C	Water Cement Ratio
KN	Kilo Newton
psi	Pound per Square Inch
ksi	Kip per Square Inch
pcf	Pound per Cubic Feet
SSD	Saturated Surface Dry
Dia.	Diameter
C-n-L	Left to Right Loading (Rightward Loading) for n^{th} Cycle
C-n-R	Right to Left Loading (Leftward Loading) for n^{th} Cycle
BUET	Bangladesh University of Engineering & Technology

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

With the rapid growth of urban population in both the developing and the industrialized countries, reinforced concrete has become a material of choice for construction because it's cheaper compared to other materials. In the construction of reinforced concrete structure, it is very important to consider the earthquake provision. Generally most of the reinforced concrete structure has been constructed without seismic provision. To facilitate such provision for the constructed structure it has been essential to strengthen the existing structure. Stronger structure can be made by new technology but strengthening the existing structure needs retrofitting of the structure by appropriate materials. For retrofitting RC structures micro concrete is now being used. The various components of the existing structure are retrofitted. In this study the column will be retrofitted by micro concrete. The column of existing structure will be widened by 50mm all around. The aim of the present study to investigate the strength improvement and performance of reinforced concrete retrofitted beam column frames under incremental cyclic horizontal load with sustained vertical load. Most of the previous researches were performed on behavior and response of structure by retrofitted with different material. Now it will be studied with micro concrete.

1.2 OBJECTIVES OF THE RESEARCH

The main objective of this thesis is to conduct experiments on two frames with retrofitted by micro-concrete and one frame without retrofit to interpret the experimental findings. The terminal objectives of the investigation are as follows:

1. To investigate the ultimate lateral load carrying capacity and the maximum lateral displacement of square RC columns strengthened using MC jacket.
2. To study the effectiveness of the applied jacketing style in terms of ultimate lateral load carrying capacity, failure patterns and compares the obtained results with that of the columns of CS.
3. To study the effect of jacket thickness on both the ultimate load carrying capacity and the lateral displacement and compare the obtained results with that of the columns of the CS.

4. To observe the response of the specimens under the strength variation with different grain size.
5. To increase the factor of safety against lateral load carrying capacity by means of retrofitting.

1.3 METHODOLOGY

To investigate the behavior of reinforced concrete frame with varying retrofitted parameters, cyclic static incremental horizontal load were provided to test the frames with sustained vertical load. Half scale RC model frames were prepared, integral with a heavily reinforced concrete base. Frames were of 1.5 m height and 2.6 m span. Then the following parameters were considered for the study:

A total of three frames were constructed for the study:

1. All three frames were constructed with same base beam cross section (300mm x 250mm)
2. All three frames were constructed with same top beam cross section (125mm x 125mm)
3. All of three frames were constructed with column section by (125mm x 125mm) at first stage
4. Before retrofitting the column section of two frames were (125mm x 125mm)
5. After retrofitting the column section of two frames were (225mm x 225mm)

Finally, the load deflection curves were compared for the considered different frames with retrofit and without retrofit.

1.4 SCOPE OF THE WORK

1. This test was done in the laboratory. Preparation of the specimens, set up of the test, loading condition, data collection, environment all were in the laboratory condition. So this might not resemble the real condition of a structure.
2. This study deals with only micro concrete as a jacketing material. The behavior of the other jacketing materials was not studied.
3. Depth of penetration of the longitudinal rebars for the retrofitting was provided in accordance with the usual practice.
4. This study considered only the static cyclic behavior of the frames. But the dynamic behavior was not considered.

CHAPTER TWO

LITERATURE REVIEW

2.1 GENERAL

This chapter presents a literature review spanning topics like of use of micro concrete in construction practice, observation of the effect of cyclic load on concrete column and frame and understanding the mechanical behavior of cyclic load on different type of structure. Since no previous study of column retrofitting by micro concrete has been made before, only the cyclic load related studies on columns and frames will be mentioned.

2.2 REINFORCED CONCRETE

Reinforced concrete is one of the most widely used modern construction materials. Concrete is "artificial stone" obtained by mixing cement, sand, and aggregates with water. Fresh concrete can be molded into almost any shape, which is an inherent advantage over other materials. Concrete became very popular in 19^{th} century; however, its limited tension resistance prevented its wide use in construction. To overcome this weakness, steel bars are embedded in concrete to form a composite material called reinforced concrete.

2.3 FORMWORK

One of the major benefits of concrete is its ability to conform to any shape that can be imagined, provided a form is designed to shape it. Formwork is used to support and control the shape of fresh concrete. The complex shapes that can be produced using concrete result in complex formwork. The formwork must be capable of handling all of the loads imposed on it through the weight and pressure of the concrete as well as any other loads imposed by personnel, materials, equipment, or environmental loads. It must also support the concrete structure until the concrete has gained strength enough to support its self weight and all imposed loads on it. Warrants for good formwork to build structure:

1. It should be strong enough to withstand all types of dead loads, live loads and superimposed loads applied on it.
2. It should be rigidly constructed and efficiently braced both horizontally and vertically, so as to retain its shape.

3. The joints in the formwork should be water-tight against leakage of cement grout.
4. Erection of formwork should permit removal of various parts in desired sequences without damage to the concrete.
5. The material of the formwork should be cheap, easily available and should be suitable for reuse.
6. The formwork should be set accurately to the desired line and levels. It should have plane and smooth surface.
7. It should rest on firm base.
8. It should rest on firm base and free from vermin and insects.

2.4 MICRO CONCRETE

Micro concrete is a dry ready mix cementations based composition formulated for use in repairs of areas where the concrete is damaged and the structure is not withstanding in earthquake or seismic vibration as well as when the area to be strengthened is restricted in movement making the placement of conventional concrete difficult. It is supplied as a ready to use dry powder which requires only addition of clean water at site to produce a free flowing non shrink repair micro concrete. This is a cementations material, with additives, which impart controlled expansion characteristics in the plastic state with reduced water demand.

2.5 CONCRETE MIX DESIGN

Concrete mix design is of two types:

1. Nominal concrete mix
2. Designed concrete mix

Nominal concrete mixes are those specified by standard codes for common construction works. These mix takes into consideration the margin for quality control, material quality and workmanship in concrete construction. Designed mix concrete suggests proportions of cement, sand, aggregates and water and admixtures based on actual material quality, degree of quality control, quality of materials and their moisture content for given concrete compressive strength required for the project. Designed mix concrete are carried out in laboratory and based on various tests and revisions in mix designs, the final mix proportions are suggested.

2.6 ADMIXURES

Chemical admixtures are the ingredients in concrete other than Portland cement, water, and aggregate that is added to the mix immediately before or during mixing. Admixtures are

required to enhance some properties of concrete such as workability, setting time etc. These admixtures also need to be considered during concrete mix design calculations for its optimum use. Their overdose can affect the properties of concrete and can cause harm to strength and durability.

2.7 CYCLIC LOAD

Cyclic loading is “generated” by earthquakes which are one of the most dangerous and destructive forms of natural hazard. Cyclic loading can be grouped into two categories; low cycle load, or a load history involving few cycles but having very large bond stress ranges. This group of loading is very common to seismic and high wind loadings. The second group relates to high cycle or otherwise known as fatigue loading. The load history in this case includes many cycles but at a low bond stress range. Offshore structures and bridge members are repeatedly subjected to such kind of load.

2.8 PREVIOUS WORKS

Literature related studies on the behavior of columns strengthening by appropriate jacketing materials subjected to cyclic loading is presented below:

Zakaria (2014) studied on his M.Sc. thesis on strengthening of square reinforced concrete columns with fibrous ultra-high performance self-compacting concrete jacketing. This research investigated the ultimate load carrying capacity and the longitudinal axial strain of square RC columns strengthened by applying three jacketing styles. All fabricated column specimens were subjected to monotonically low-rate of uniaxial compression loading. Three jacketing styles namely G1, G2 and G3 have been studied experimentally to investigate the effectiveness of every jacketing style. Fibrous UHPSCC was applied as a jacketing material withG1 and G3 jacketing styles, whereas Non-Fibrous UHPSCC jacket was applied withG2 jacketing style.G1, G2 and G3 jacketing styles consisted of 27 column specimens in total (9 column specimens for each jacketing style), while the UC and MC reference columns consisted of 12 column specimens. All fabricated column specimens were tested at IUG Soil and Materials laboratory. Strengthening RC columns by applying Fibrous UHPSCC as a jacketing material was effective and has reduced the total strengthened column sections. The Fibrous UHPSCC can flow easily into narrow form sections without segregation or honeycombing problems, even in cases of steel congested sections. The relationships between the applied load and axial strain of the tested column specimens were typical, a linear behavior up to one third of the ultimate load carrying capacity followed by a nonlinear

behavior until failure. Applying several jacket Thicknesses of 25, 30 and 35 mm with G1, G2 and G3 jacketing styles improved considerably the ultimate load carrying capacity in almost a similar rate with respect to the rate of increase in jacketing area. The G2-25, G2-30 and G2-35 also gained significant increase in ultimate load Carrying capacity higher 3.5, 4.2, and 4.8 times than the UC reference column respectively and higher about 2.0 times than the MC reference columns. The failure modes of UC and MC reference columns were ductile giving longitudinal Axial strains of 0.0032 and 0.0033 respectively that was attributed to the application of a normal strength concrete (NSC) in casting the reference columns. The failure mode of G2 jacketed column specimens was brittle. That was observed by crushing loudly giving no previous warning signals.

Takiguchi and **Abdullah (1999)** had performed experimental study on reinforced concrete column strengthened with Ferro-cement jacket. Strengthening method using circular fibrocement jacket to improve the confinement of a substandard column was investigated and compared with CSs and different strengthening methods. Five 1:6 scale model square columns were constructed and have been tested under constant axial load while simultaneously being subjected to cyclic lateral load. The loading system used in this experiment displaced the tested columns in a double bending. Two columns were tested as CSs; one column was strengthened with circular fibrocement jacket and was compared with those of other two identical square RC columns strengthened circularly with steel plate and carbon fiber. The CSs suffered shear failure and significant degradation of strength during testing whereas the strengthened columns showed a ductile flexural response and higher strength. The test results indicate that circular fibrocement jacket can be an effective alternative material to strengthen reinforced concrete column with in adequate shear resistance. All specimens were tested under cyclic lateral load while simultaneously being subjected to constant axial load of 62 KN. Unless failure occurred at an earlier stage, two full cycle lateral load followed by monotonically lateral load in push direction until the column specimens could not maintain the axial load were applied to every specimen. The applied cyclic loading was displacement-controlled.

Zarnic and **Tomazevic (1984)** studied the Behavior of masonry infill reinforced concrete frames subjected to cyclic lateral loading. They find that masonry infill stiff reinforced concrete frame behaves as an unique structural system until diagonal crack occur in the infill and after cracking frame takes significant part of the lateral load, until its column fail in shear.

Abrams (1987) conducted tests on eight small-scale joints, four medium-scale joints and six large-scale joints. Specimens were subjected to reversals of lateral force to study scale correlations for nonlinear hysteresis properties. He had concluded that stiffness deterioration was the highest for small-scale specimens as a result of weaker bond between model reinforcement and mortar. One-quarter scale specimens showed force deflection response similar to those of large-scale specimens. He recommended that minimum usable scale for testing of isolated reinforcement concrete components be a quarter. Also studied the effect of axial load on the reversed lateral cyclic loading of columns and found that the additional axial load increasers the stiffness, flexural strength and shear capacity. They found that the shape of the hysteretic loop was influenced by the range of axial force variation and the rate of change of axial force with lateral deflection

Yunfei et al. (1988) conducted a detail study on a series of reinforced concrete beam column joints. Experiment shows column joint at base is the most critical position affecting the ductility of the total frame.

Saatcioglu and **Ozcebe (1989)** tested full scale columns under slowly applied lateral load reversals. Test parameters were axial load, confinement reinforcement and deformation path. They found increased stiffness degradation and early strength degradation with addition of axial loads. The authors concluded that selection of a proper confinement configuration is a more feasible approach than the reduction in hoop spacing alone to achieve the same level of ductility Mo and Wang (2000) conducted experiments on RC columns with various tie configurations by reversed cyclic loading. They proposed transverse reinforcement configurations with alternate ties to improve seismic performance. It was found from the test results that the proposed configuration of transverse reinforcement provides comparable or improved seismic performance in terms of member ductility and energy dissipation capacity to those usually used in design, and the requirement for compression lap splice in the ties is also adequate when the proposed alternate configuration of transverse reinforcement is used.

Marjani and **Ersoy (2002)** studied the behavior of structural frames in-filled with masonry walls under seismic loads. For this purpose, six two story, one bay brick in-filled frames were tested under reversed cyclic loading simulating seismic action. Effects of plaster and concrete quality on in-filled frame behavior were the main parameter investigated. This study showed that the strength increase of hollow clay tile infill frame as compared to the bare frame is about 240% for specimens with non-plastered infill and 300% for the plaster one. It was found that plaster also improve the ductility and delays the diagonal cracking of infill. For

plaster infill frame crack was at about 20% higher load as compared to the non-plastered specimen.

Thammanoon and **Hiroshi (2005)** conducted a study to explore the ductility of reinforced concrete columns subjected to constant axial load and reversed cyclic loading. For the test displacement control was applied at each loading step and three cycles of reversed cyclic loading was performed. From experimental results, it was found that the ductility capacity is linearly inverse proportional to axial load level (N/N @balance) and buckling initiation of longitudinal reinforcement is also linearly inverse proportional to axial load normalized by axial capacity (N/N, capacity).

Mukherjee and **Joshi (2005)** carried out an investigation on the performance of reinforced concrete beam - column joints under cyclic loading. Joints were casted with adequate and deficient bond of reinforcements at the beam-column joint. FRP sheets and strips have been applied on the joints in different configurations. The columns were subjected to an axial force while the beams were subjected to a cyclic load with controlled displacement. The amplitude of displacement is increased monotonically using a dynamic actuator. The hysteretic curves of the specimens were plotted. The energy dissipation capacity of various FRP configurations was compared. In addition, the CSs were reused after testing as damaged specimens that are candidates for rehabilitation. The rehabilitation was carried out using FRP and their performance was compared with that of the undamaged specimens.

CHAPTER THREE

MATERIAL PROPERTIES

3.1 GENERAL

The typical reinforced cement concrete frame was constructed by stone chips, sand, cement, steel and admixtures. The drinkable water was used for all varying purpose. All the materials were chosen from reliable source and by suitable method. Wooden plucks were used for formwork.

3.2 CEMENT

For the construction the ordinary Portland cement was used. Specification and composition of cement by the manufacturer:
28^{th} days cube strength 42.5 N by ASTM C595, Clinker: 65-79%, Slag, Fly ash & Limestone: 21 – 35% Gypsum: 0-5%, specific gravity 3.15 and unit weight 197 pcf.

3.3 SAND

For the construction the Sylhet sand was used. Sylhet sand FM is 2.5. Sand was free from clay.

3.4 REINFORCEMENT

Three types of reinforcing bars were used in the construction of seven specimens specified as 10 mm, 12 mm and 16 mm bar. 400W steel bars were used as reinforcement with a characteristic yield stress of 400 MPa verified by Universal Testing Machine. The frames in all groups were characterized by steel reinforcement ratio = A_s/bd. Material properties provided by manufacturer are presented in the table 3.1.

Table 3.1: Material Properties Tested By Laboratory

Material	Diameter	Yield Strength MPa (Min)	Ultimate Strength MPa	Elongation %
400 W	10 mm	438.5	462	15
400 W	10 mm	438.5	682	14
400 W	10 mm	401.9	621	15
400 W	12 mm	414.5	651.8	14
400 W	12 mm	457.0	711	15

400 W	12 mm	448.5	694	14
400 W	16 mm	409.5	598	14
400 W	16 mm	435.3	674	15
400 W	16 mm	443.0	701	15

3.5 CONCRETE

The concrete used for the preparation of frames was made using the Ordinary Portland Cement, Sylhet sand as the fine aggregate and stone chips as the coarse aggregate with the maximum size of 12.5 mm. The aggregates used for concrete work are shown in the figure 3.1 and figure 3.2.

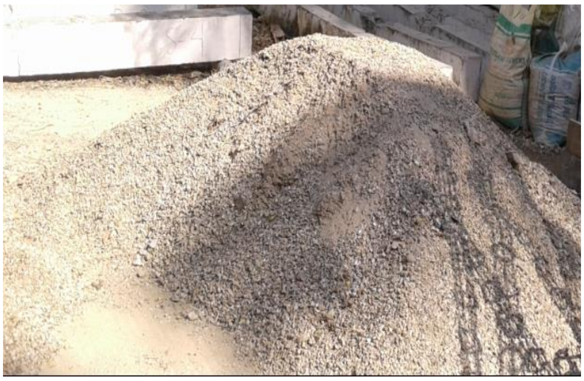


Figure 3.1: Coarse Aggregate

Figure 3.2: Fine Aggregate

3.6 CONTROL SPECIMEN

It was built with nominal mix design by the ratio of (cement: sand: coarse aggregate) 1: 1.5: 3 and the W/C ratio 0.46 which has been optimized by trial mix for the desired slump value 70 mm, as shown in Figure 3.3 and Figure 3.4.

Figure 3.3: Slump Test for Normal Concrete

Figure 3.4: Slump Test Value 70 mm

Table 3.2: Compressive Strengths of Concrete Cylinders for Control Specimen

7^{th}	Specimen	Dia. (inch)	Area ($inch^2$)	Area (mm^2)	Observed Load (KN)	Actual Load (1.006x +	Stress (MPa)	Stress (psi)	Strength (psi)

day						1.226) (KN)			
	1	3.97	12.37	7731.76	80	81.71	10.5	1520	
	2	3.98	12.42	7762.23	90	91.77	12	1740	1620
	3	3.97	12.37	7731.76	84	85.73	11	1600	
14^{th} day	Specimen	Dia. (inch)	Area ($inch^2$)	Area (mm^2)	Observed Load (KN)	Actual Load (1.01X-116.2) (KN)	Stress (MPa)	Stress (psi)	Strength (psi)
	1	4	12.57	7854	235	121.15	15.5	2250	
	2	4	12.57	7854	223	109.03	14	2030	2150
	3	4	12.57	7854	232	118.12	15	2175	
28^{th} day	Specimen	Dia. (inch)	Area ($inch^2$)	Area (mm^2)	Observed Load (KN)	Actual Load (1.026X-11.59) (KN)	Stress (MPa)	Stress (psi)	Strength (psi)
	1	4.12	13.31	8320.95	160	152.57	18.5	2685	
	2	4.12	13.31	8320.95	150	142.31	17	2465	2680
	3	4.12	13.31	8320.95	174	166.93	20	2900	

A measurement on hardened concrete was conducted as compressive strength according to standard ASTM C39. The compressive strength for each concrete casting was determined on 3x3 standard 100 mm x 200 mm concrete cylinders. The specimens were in the moulds for 24 hours; thereafter they were taken out from their moulds and stored at 100% relative humidity until testing. The compressive strength was tested after 7, 14 and 28 days and which is presented in table 3.2.

3.7 RETROFITTED SPECIMENS

It was built with nominal mix design by the ratio of (Cement: Fine Aggregate: Coarse Aggregate) 1: 1: 1.5 and 1:1.25:1.5. The coarse aggregate size was 6.3 mm passing with 2.36 mm retaining for the 1:1:1.5 volumetric ratio and 9.5 mm passing with 4.75 mm retaining for the 1:1.25:1.5 volumetric ratio. The water cement ratios are 0.25 and 0.29 which has been optimized by trial mix for the desired fluidity. W/C was decreased by using admixtures dose of 9ml/ kg of cement and the slump was found to be 250mm. Slump test of micro concrete and preparation of cylinders for compressive strength test are shown in Figure 3.5 and Figure 3.6 respectively. 2x2 standard 100 mm x 200 mm concrete cylinders were tested after 7th and 28th day and the results are presented in table 3.3.

Table 3.3: Cylinder Test Results for Strength Test of Micro Concrete

	Ratio	Specimen	Dia. (inch)	Area (mm^2)	Load observed (KN)	Actual (1.014x-12.133)KN	Stress (MPa)	Stress (psi)	Strength (psi)
7th day	1:1:1.5	1	3.95	7914	325.2	317.62	40	5940	5800
		2	3.95	7914	310.8	303.02	38	5670	
	1:1.25:1.5	1	4.03	8230	276.2	267.93	33	4820	4610
		2	4.05	8326	256.6	248.06	30	4410	
	Ratio	Specimen	Dia. (inch)	Area (mm^2)	Load observed (KN)	Actual (1.026x-11.59) KN	Stress (MPa)	Stress (psi)	Strength (psi)
28th day	1:1:1.5	1	4.08	8423	462	462.42	55	8125	8160
		2	4.08	8423	466	466.53	55	8200	
	1:1.25:1.5	1	4.05	8294	350	347.51	42	6200	6300
		2	4.05	8294	360	357.77	43	6380	

Figure 3.5: Slump Test for Micro Concrete

Figure 3.6: Preparation of Cylinder for Strength Test

3.8 ADMIXURES

Liquid admixture for reducing water-cement ratio was used as dozes of 9ml/kg of Ordinary Portland Cement in both specimens. The Details of admixtures are attached in the Appendix-B.

3.9 CHEMICAL BINDER (EPOXY)

Chemical binder was used for proper binding between concrete and the steel. The properties of the binder are provided in the Appendix-B.

CHAPTER FOUR

METHODOLOGY

This chapter presents the experimental procedure of this research consisting of specimen preparation of half scale models of concrete frames. To study the effect of jacketing, two reinforced concrete frames with different column section and micro concrete used for jacketing have been tested. The test setups and procedure are discussed below.

4.1 SKETCH OF THE MODEL

4.1.1 Geometric Properties of the Frame Models

To identify the effect of seismic loading on retrofitted column, a one bay frame of the bottom story of a six storied building structure was selected as shown in figure 4.1. The model was designed in half scale of the original structure.

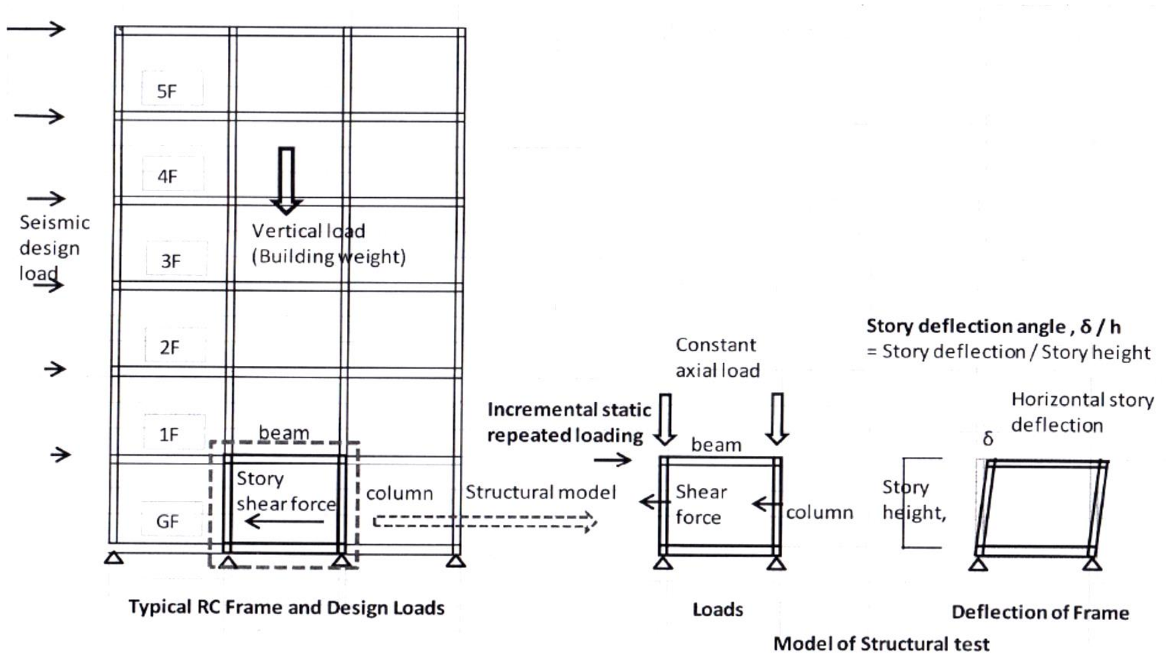


Figure 4.1: Selection of Model Specimen

Two vertical point loads were applied to get the effect of sustained gravity load along with a horizontal incremental static repeated loading for seismic effect. All frames had the span length of 2.6m and total height of 1.5m. Figure 4.2 shows the layout and dimensions of the frames and the structural elements. Detail geometry and reinforcement of the frame is shown in figure 4.3 and cross sectional details of different frame parts are presented in table 4.1

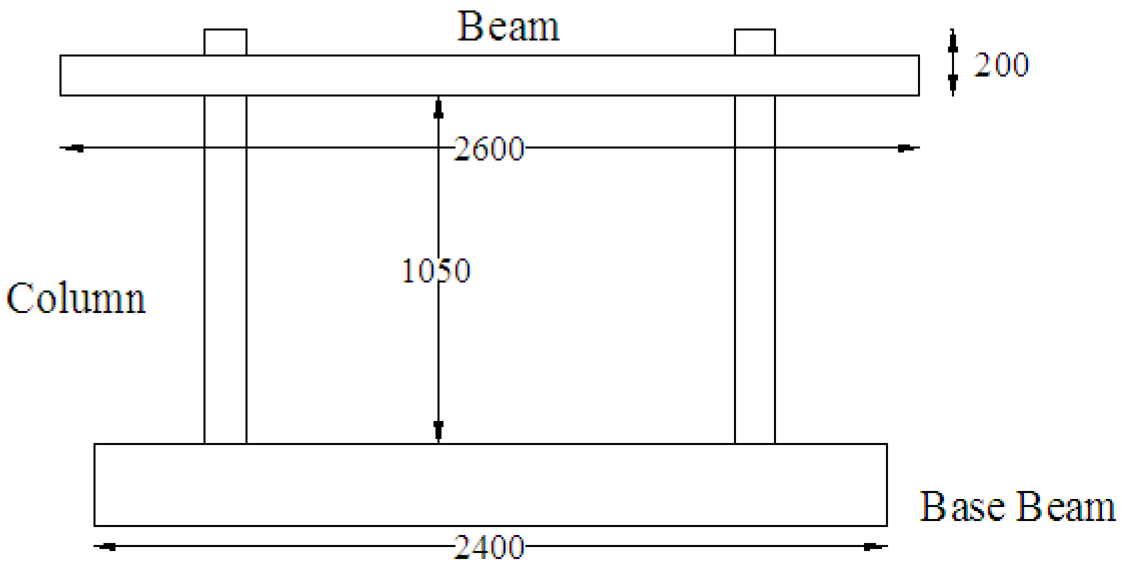


Figure 4.2: Length of the Different Components

Table 4.1: Dimension of the Model

Control Specimen with column size 125 mm x 125 mm	Specimen with material strength adjusting to existing building condition
Retrofitted Specimens with column size 225 mm x 225 mm	Specimen with material strength higher [8160 psi]
	Specimen with material strength lower [6300 psi]

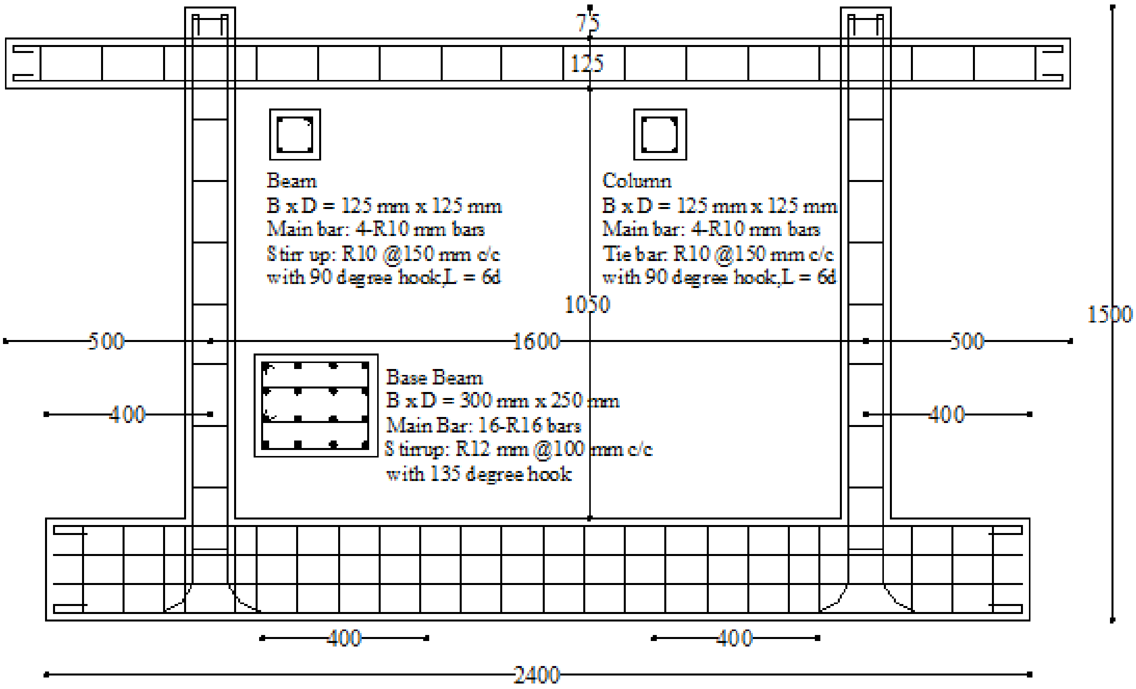


Figure 4.3: Reinforcement Detailing of the Control Specimen

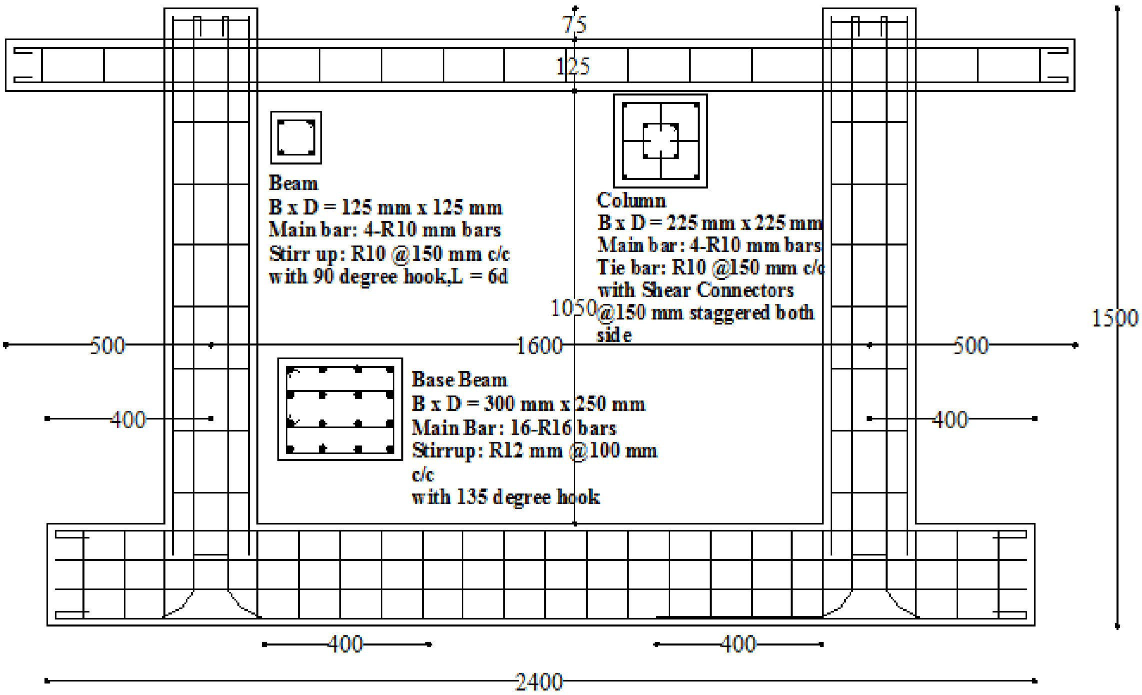
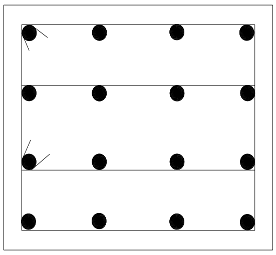
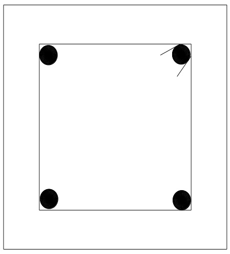
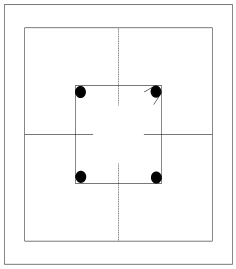
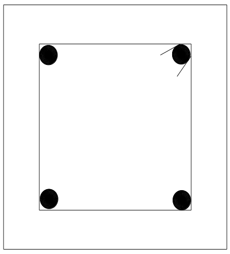


Figure 4.4: Reinforcement Detailing of the RetroFitted Specimens

Table 4.2: Cross Section of Different Frame Component

Frame Part	Cross Section	Reinforcement Detail
Base Beam		Base Beam B x D = 300mm x 250 mm Main bar: 16-R16 Stirrup: R12 @100 with 135 degree hook Clear cover = 20 mm
Column of CS		Column B x D = 125 mm x 125 mm Main bar: 4-R12 Hoop: R8 @150 with 90 degree hook, L = 6d Clear cover = 20 mm
Column of RSs		Column B x D = 225 mm x 225 mm Main bar: 4-R12 Hoop: R10 @150 with 90 degree hook, L = 6d Clear cover = 20 mm
Beam		Beam B x D = 125 mm x 125 mm Main bar: 4R10 Stirrup: R10 @150 mm with 90 degree hook, L = 6d Clear cover = 20 mm

Frames were constructed in two types mainly based on column cross-section. Control type of specimen was built with column size of 125 mm x 125 mm and the retrofitted type of specimens was built with the column size of 225 mm x 225mm.

4.2 TYPICAL MODEL

There was one Control Specimen

Column size: 125mm x 125mm

Main Bars: 4-R12 mm deformed bar

Shear Reinforcement: R10 mm @150 mm with 90 degree hook

Beam size: 150 mm x 150 mm

Main Bars: 2-R12 mm top bar and 2-R10 mm bottom bar
Shear Reinforcement: R10 mm @150 mm with 90 degree hook

Base Beam size: 300 mm x 250 mm
Main Bars: 4-R16 mm top bar and 4-R16 mm bottom bar
Shear Reinforcement: R12 mm @100 mm with 135 degree hook
Beam -Column Connection: No shear reinforcement

There were two Retrofitted Specimens

Column size: 225 mm x 225 mm (125 mm x 125 mm core concrete and each side extended by 50 mm)
Main Bars: 8-R12 mm deformed bar
Shear Reinforcement: R10 mm @150 mm with 90 degree hook
Shear connectors: R10 @ 150 mm staggered on both sides

Beam size: 150 mm x 150 mm
Main Bars: 2-R12 mm top bar and 2-R10 mm bottom bar
Shear Reinforcement: R10 mm @150 mm with 90 degree hook
Base Beam size: 300 mm x 250 mm
Main Bars: 4-R16 mm top bar and 4-R16 mm bottom bar
Shear Reinforcement: R12 mm @100 mm with 135 degree hook
Beam -Column Connection: No shear reinforcement

4.3 SPECIMEN PREPARATION

4.3.1 First Stage

Three Frame specimens were prepared horizontally. In practical construction practice all the components were casted monolithically. Step by step construction process is described below: Base beams were constructed of length 2400mm and a cross section of 300 mm x 250 mm. Columns and beams were constructed with length of 1250 mm and 2600 mm consecutively. Both are of 125 mm x 125 mm cross section connected by a joint. Formwork was constructed to support the freshly placed concrete and the reinforcement. Basic concerns were the accuracy of the design, pertaining to length and shape as well as the finish of the frame specimens. Steel wires were used to keep the longitudinal reinforcement in place. A number of small cement concrete blocks were used on the inner face and on two sides of the formwork to maintain 20 mm clear cover. Vibrator and tamping rod of 25 mm diameter was used for proper compaction. Element used in the construction of the formwork was 25 mm thick wood. The formwork was removed after 7 days of casting and covered with wet gunny

sacks to maintain the moisture level. The frame specimens were cured with water 2 times of everyday. Construction process is shown step by step in the following figures:

Figure 4.5: Preparation of the Formwork

Figure 4.6: Preparation of the Reinforcement Skeleton

Figure 4.7: Sieving of 12.5 mm Downgrade Coarse Aggregate

Figure 4.8: SSD for 24 Hours.

Figure 4.9: Mixing of Concrete

Figure 4.10: Casting of Concrete

Figure 4.11: Base Beam Tampering by Tamping Rod

Figure 4.12: Base Beam Tampering by Vibrator

Figure 4.13: Construction of Column

Figure 4.14: Construction of Beam

Figure 4.15: Frame After Casting of Fresh Concrete

Figure 4.16: Frame after Casting of Fresh Concrete

Figure 4.17: Preparation of Cylinders For The Testing

Figure 4.18: Curing of the Specimens by Gunny Sacks

4.3.2 Second Stage

In the second stage of the construction process, the two specimens were retrofitted by micro concrete of varying size. One specimen was retrofitted by micro concrete of lower strength [6300 psi] and another was retrofitted by higher strength micro concrete [8160 psi] to observe the response for the cyclic load. The two specimens were extended by 50 mm on each side of the column only. Step by step process of retrofitting is discussed below:

Figure 4.19: Removal of Formwork for Retrofitting

Figure 4.20: Drilling for Insertion of Rebars and Shear Connectors

Formworks were removed after 7 days for retrofitting the specimens. It was decided by the cylinder test result that the specimens will carry its self-weight after removing the formwork. For proper anchorage between hardened concrete and freshly placed micro concrete shear connectors were inserted up to 38 mm depth. The shear connectors were deformed bar of 10 mm diameter. Figure 4.21 shows that how ties and shear connectors were placed in the columns.

Figure 4.21: Placement of Ties And Shear Connectors

Figure 4.22: Epoxy

Figure 4.23: Insertion of Shear Connectors with Epoxy

Figure 4.24: Welding of Ties and Shear Connectors

Figure 4.22 shows chemical binder and Figure 4.23 shows use of this for the proper binding of hardened concrete with shear connectors and insertion of shear connectors with chemical binder. Figure 4.24 shows welding of ties and shear connector for proper binding between them and Figure 4.25 shows welded ties and shear connectors after completion of welding.

Figure 4.25: After Completion of Welding

Figure 4.26: Formwork for Placement of Micro-Concrete

In the process of retrofitting, for this frame, it was difficult to place micro concrete around the column for extending the each side by 50 mm. For that reason, some part of formwork was open to facilitate the placement of micro concrete which is shown in Figure 4.26.

Figure 4.27: Placement of Micro Concrete

Figure 4.28: Tamping by Rod

For the easement of compaction tamping was done by rod instead of mechanical vibrator as it was not feasible in this case and this is shown in Figure 4.28. Process of concreting for retrofitting is shown in the following figures:

Figure 4.29: Completion of Placement upto a Mark

Figure 4.30: Closing of Formwork

Figure 4.31: Placement of Micro Concrete from Top

Figure 4.32: Final Finishing

After full completion of the placement of micro concrete the specimens were cured 2 times in a day and it was continued upto 28 days. Gunny sacks were used to facilitate the curing. After the curing the specimens were white washed to find out the crack and their absolute location. Figure 4.33, figure 4.34 and figure 4.35 show the prepared specimens prior to test.

Figure 4.33: CS

Figure 4.34: RS-1

Figure 4.35: RS-2

4.4 TEST SET-UP, INSTRUMENTATION AND DATA ACQUISITION

The control frame was tested under horizontal incremental cyclic loading along with constant axial load. The control specimen was tested under cyclic loading conditions displacing it laterally, along the axis of the beam. Loading and unloading were applied in the positive (rightward) and negative (leftward) direction for 1st cycle. A constant loading rate per cycle was maintained until the specimens experienced significant loss of capacity. The loading history applied to the specimens is shown in figure 4.36.

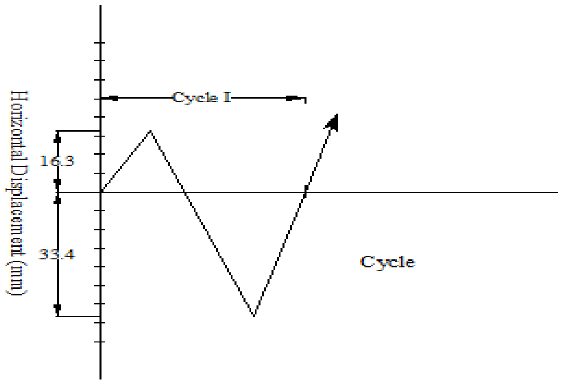


Figure 4.36: Loading History for Control Specimen

The retrofitted frames were also tested under horizontal incremental cyclic loading along with constant axial load. The specimens were tested under cyclic loading conditions displacing them laterally, along the axis of the beam. Loading and unloading were applied in the positive

(rightward) and negative (leftward) direction for 4 mm displacement in 1st cycle. Then upto 4th cycle the increment was 2 mm. For 5th and 6th cycle the increase in displacement was 3 mm and 3.5 mm respectively. For 7th cycle the loading was continued upto failure of the specimens. The loading history applied to the specimens is shown in the figure 4.37.

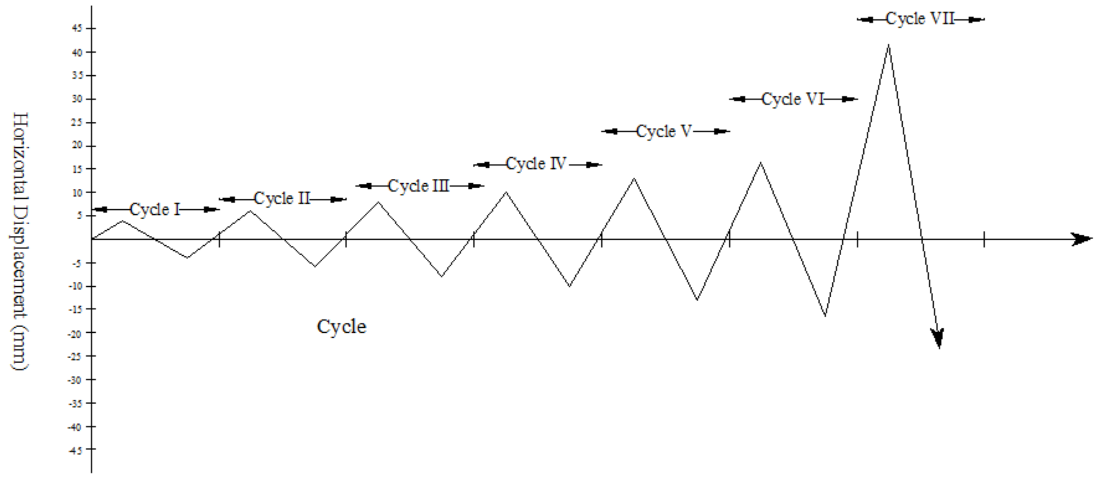


Figure 4.37: Loading History for Retrofitted Specimens

CHAPTER FIVE

RESULTS OF EXPERIMENTS

5.1 INTRODUCTION

This chapter summarizes the qualitative and quantitative experimental results from the test specimens control specimen, retrofitted specimen-1 and retrofitted specimen-2. The qualitative results include photographs of each specimen through the course of testing and displaying the crack patterns. Loads corresponding to displacements and different crack history were recorded for producing the quantitative results.

5.2 TESTING PROCEDURE

After curing, the specimens were carried away to set into the Hydraulic Testing Machine cautiously to elude any significant damages. The crane and the trolley were used to carry with appropriate workman. The loading hydraulic jacks were anchored into position before the commencement of each test. The vertical hydraulic jacks were set in their position at the top of the column and the horizontal hydraulic jacks were linked to the side face of beam. Before applying the axial load, two dial gauges were set and readings were taken as reference points to determine the deflection throughout the loading regime. A video extensometer was also used to record the data continuously. The vertical hydraulic jacks were first loaded to a combined force of 20 ton, 10 ton on each column top. Dial gauge readings were also recorded after imposing the vertical load to determine the amount of compressive shortening. The horizontal hydraulic jacks were responsible for imposing the cyclic displacements to the specimen through complete cycles. All cycle consisted of first loading and unloading the specimens toward the positive (rightward) direction hereafter referred to as the negative (leftward) direction. The displacements were monitored by two dial gauges. One dial gauge was located at the left beam-column joint and another one was at the right beam-column joint. Testing of all three specimens did not commence soon after casting. Table 4.1 presented the age of the specimens at the time of testing date.

Table 5.1: Age of Testing Specimens.

Specimen	Age of Specimen at Testing day (Days)
CS	67
RS-1	60 (after retrofitting)
RS-2	64 (after retrofitting)

5.3 CRACKING PATTERN

All three specimens exhibited different cracking patterns throughout the course of testing. Figure 5.1 is a photograph of a specimen just prior to testing.

Figure 5.1: Initial State of Test Specimen (CS)

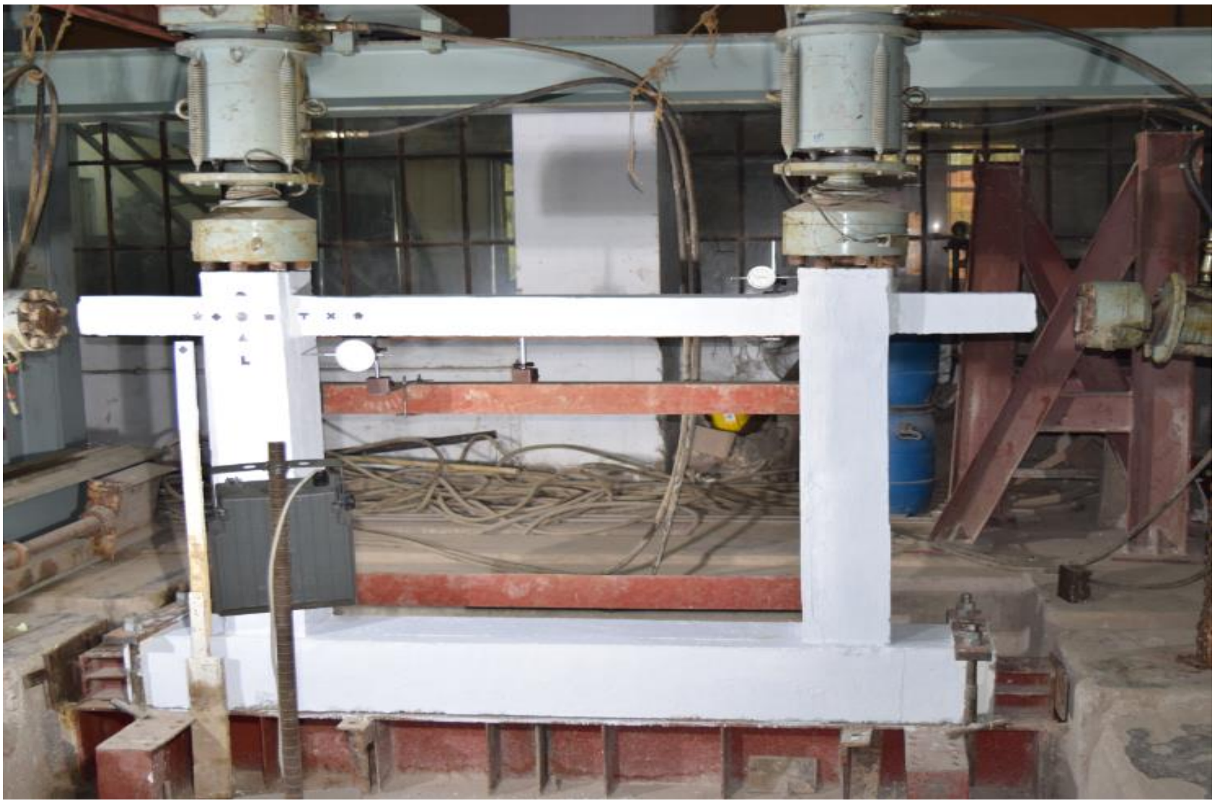


Figure 5.2: Initial State of Test Specimen (RS-1)

Figure 5.3: Initial State of Test Specimen (RS-2)

5.4 TEST RESULT OF ALL THREE SPECIMENs

5.4.1 Test Result of Control Specimen

The cracks marked in red were those that surfaced during rightward loading and the cracks in black colour were for unloading. The green marked cracks represented the cracking that appeared during the leftward loading, as shown in Figure 5.4 to Figure 5.10. The test of CS was accompanied with its very first crack at positive first cycle loading at right column with 1 ton load and corresponded to a displacement of 1.1 mm.

Figure 5.4: Final Crack Pattern of CS

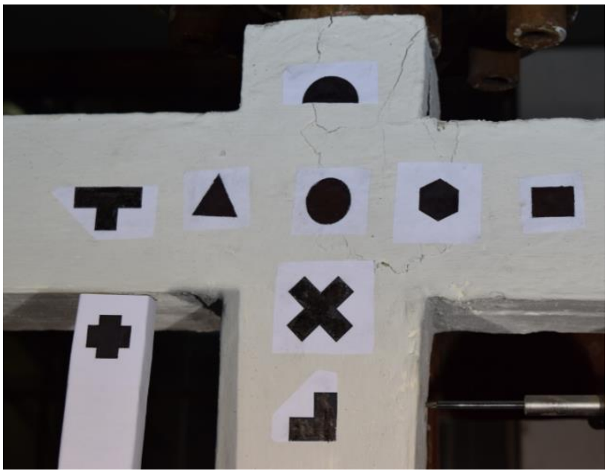


Figure 5.5: Crack in Left Beam Column Joint

Figure 5.6: Crack in Right Beam Column Joint

Figure 5.7: Crack in Left Column after Failure

Figure 5.8: Crack in Left Column after Failure

Figure 5.9: Crack in Right Column after Failure

Figure 5.10: Crack in Right Column after Failure

5.4.2 Test Result of Retrofitted Specimen-1

The cracks marked in black were those that surfaced during rightward loading and unloading. The red marked cracks, represented the cracking that appeared during the leftward loading and unloading, as illustrated in Figure 5.11 to Figure 5.19.The test of RS-1 was accompanied with its very first crack at positive first cycle loading at left column and at base beam near right column with 4.5 ton load and corresponded to a displacement of 2.8 mm.

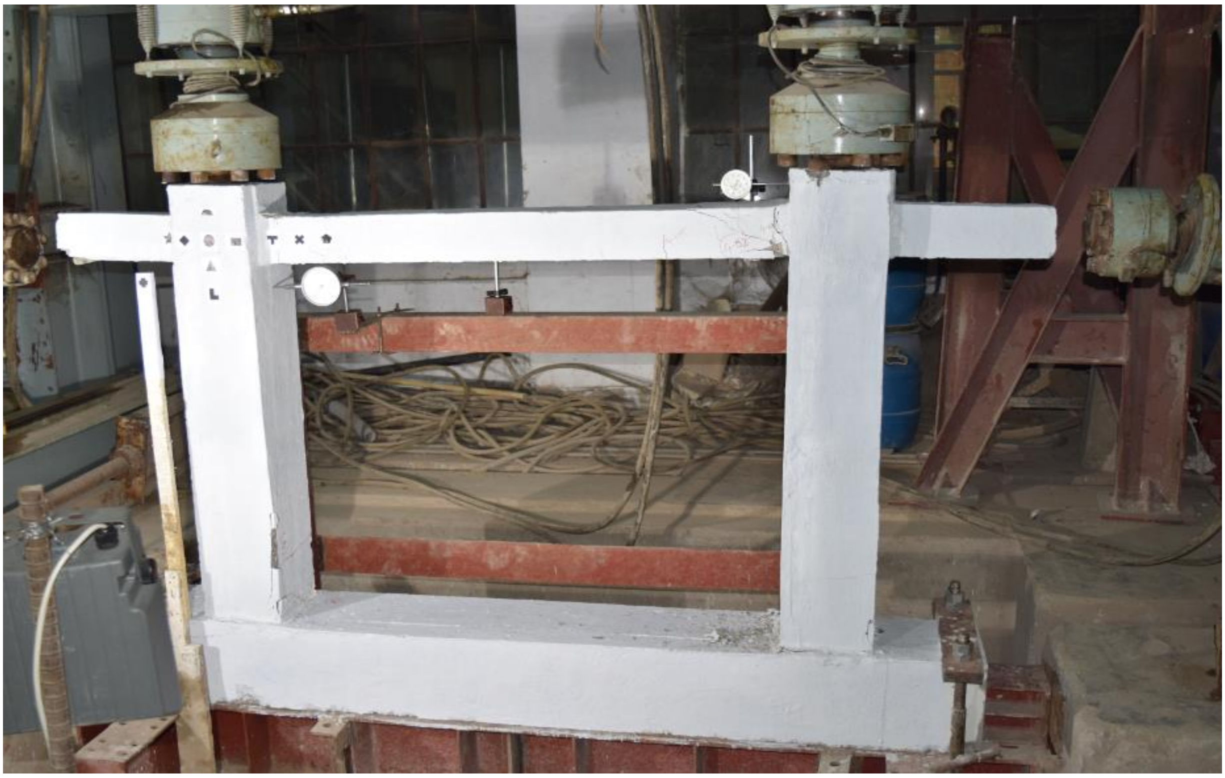
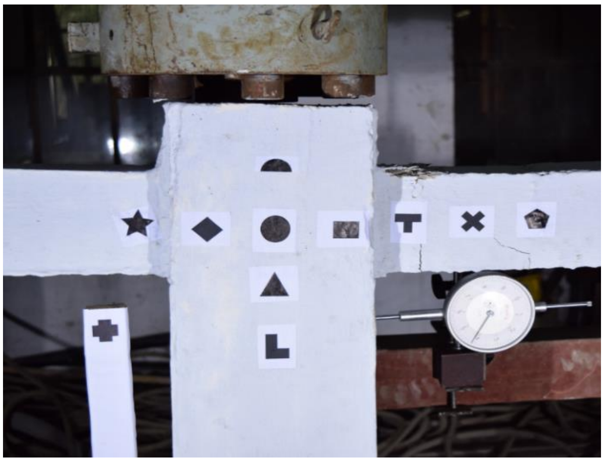


Figure 5.11: Final Crack Pattern of RS-1



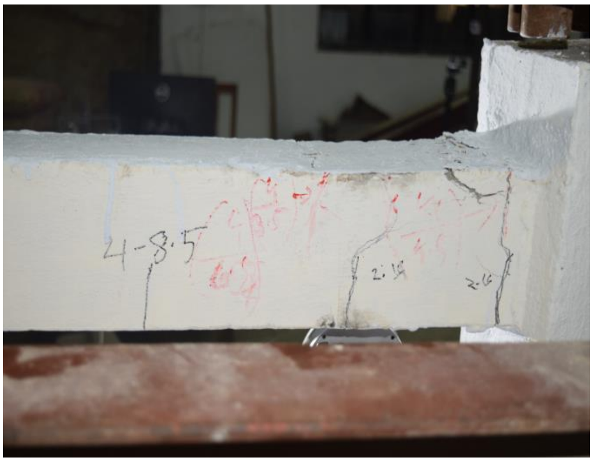


Figure 5.12: Crack in The Front of Left Beam Column Joint

Figure 5.13: Crack in The Back of Left Beam Column Joint

Figure 5.14: Crack in the Front of Right Beam Column Joint

Figure 5.15: Crack in the Back of Right Beam Column Joint

Figure 5.16: Crack in the Bottom of Left Column after failure

Figure 5.17: Crack in the Bottom of Left Column after failure

Figure 5.18: Crack in the Bottom of Right Column after failure

Figure 5.19: Crack in the Bottom of Right Column after failure

5.4.3 Test Result of Retrofitted Specimen-2

The cracks marked in black were those that surfaced during rightward loading and unloading. The red marked cracks, represented the cracks that appeared during the leftward loading and unloading, as illustrated in Figure 5.20 to Figure 5.26. During the test of RS-2, its very first crack was found at positive first cycle loading at the joint of base beam and left column with 6 ton load and corresponded to a displacement of 4 mm.

Figure 5.20: Final Crack Pattern of RS-2

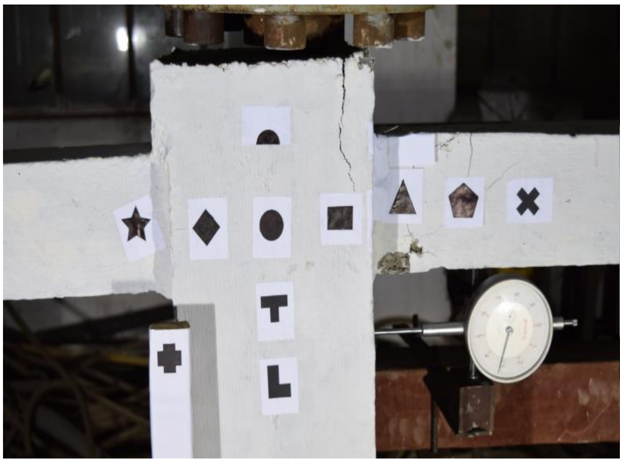


Figure 5.21: Crack in the Front of Left Beam Column Joint

Figure 5.22: Crack in the Back of Left Beam Column Joint

Figure 5.23: Crack in the Front of Right Beam Column Joint

Figure 5.24: Crack in the Back of Right Beam Column Joint

Figure 5.25: Crack in the Bottom of Left Column after Failure

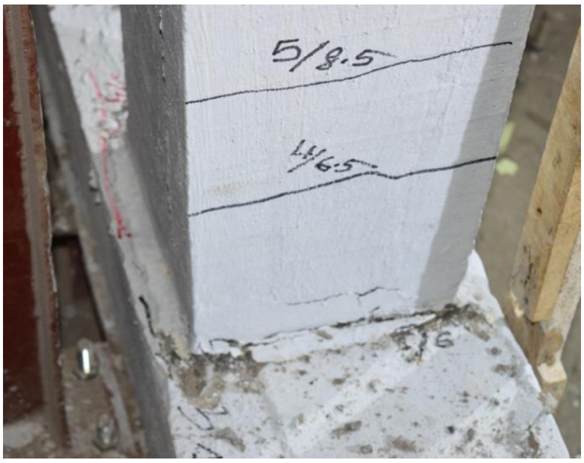


Figure 5.26: Crack in the Bottom of Left Column after Failure

5.5 THEORETICAL LATERAL LOAD CAPACITY OF CONTROL SPECIMEN

To determine the lateral load capacity of the CS frame, it was analysed by ETABS. P-M interaction diagram for column was generated and by using this lateral load capacity was found to be 1.07 ton. Figure 5.27 shows the P-M interaction diagram and a point inside the curve representing the axial load and moment for a specific lateral load which denotes the capacity of the frame.

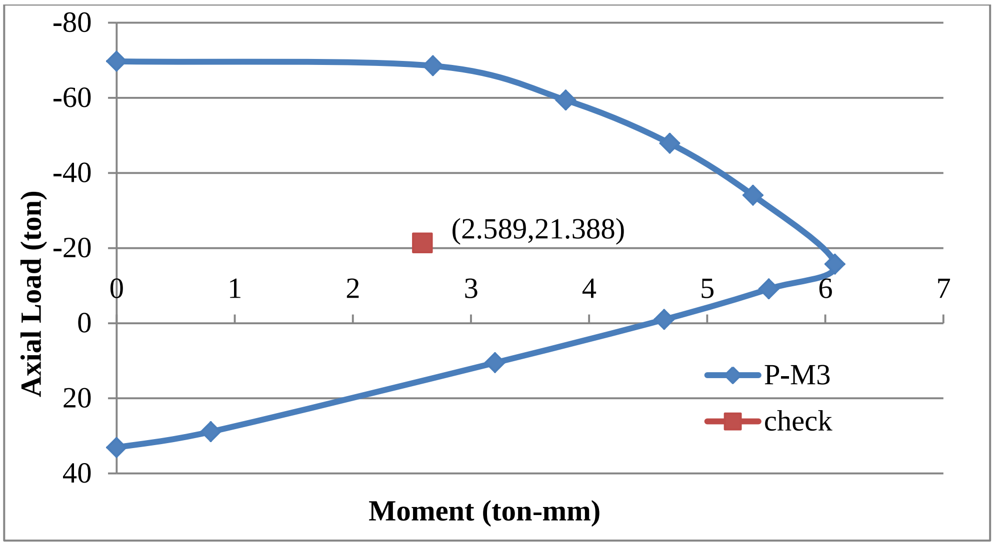


Figure 5.27: P-M Interaction Diagram

5.6 LOAD-DEFORMATION RESPONSE

Load-deformation responses of all three specimens were monitored by two dial gauges throughout each test specimen. One dial gauge was placed 65 mm below the top beam at the inner face of the column and the other one was placed 50 mm above the top beam at the inner face of the column to record the lateral displacement. For testing of CS, the test was terminated before the completion of the first cycle at 33.4 mm displacement. The RSs were loaded up-to 41 mm of displacement and the specimens failed. The testing of RSs was terminated before the 7^{th} cycle at 41 mm displacement because of separation of dial gauge from the specimens. Figure 5.27 represents the load-deformation response of the CS and the Figure 5.28 and figure 5.29 provide the load-deformation responses for the RSs. [The responses from dial gauges are available in the Appendices.]

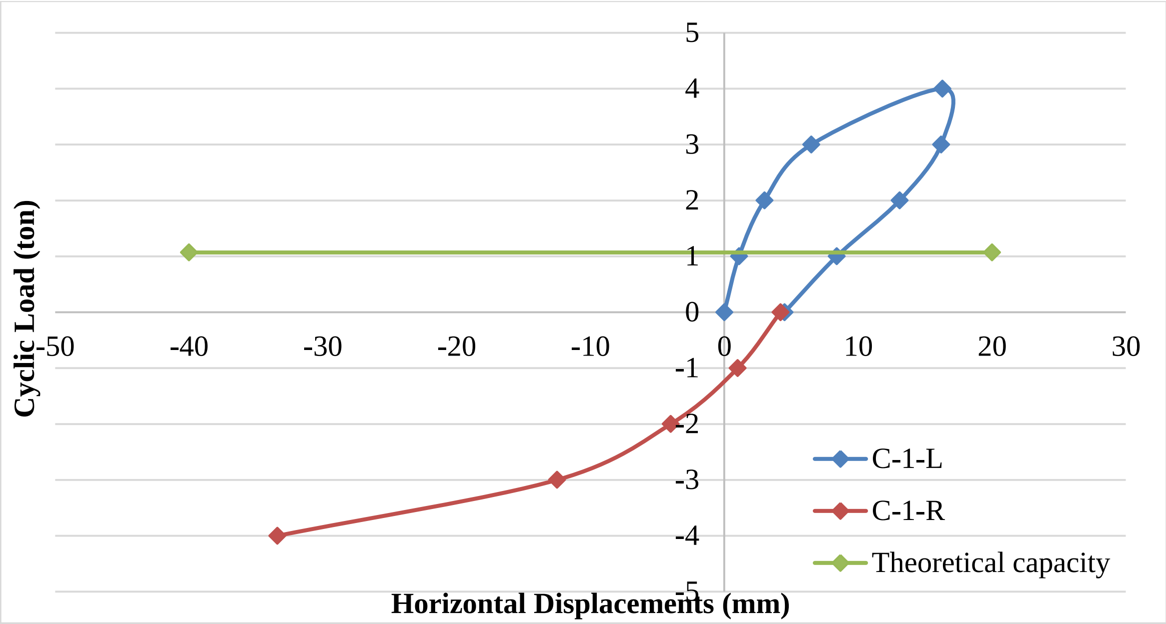


Figure 5.28: Load-Deformation Response of CS

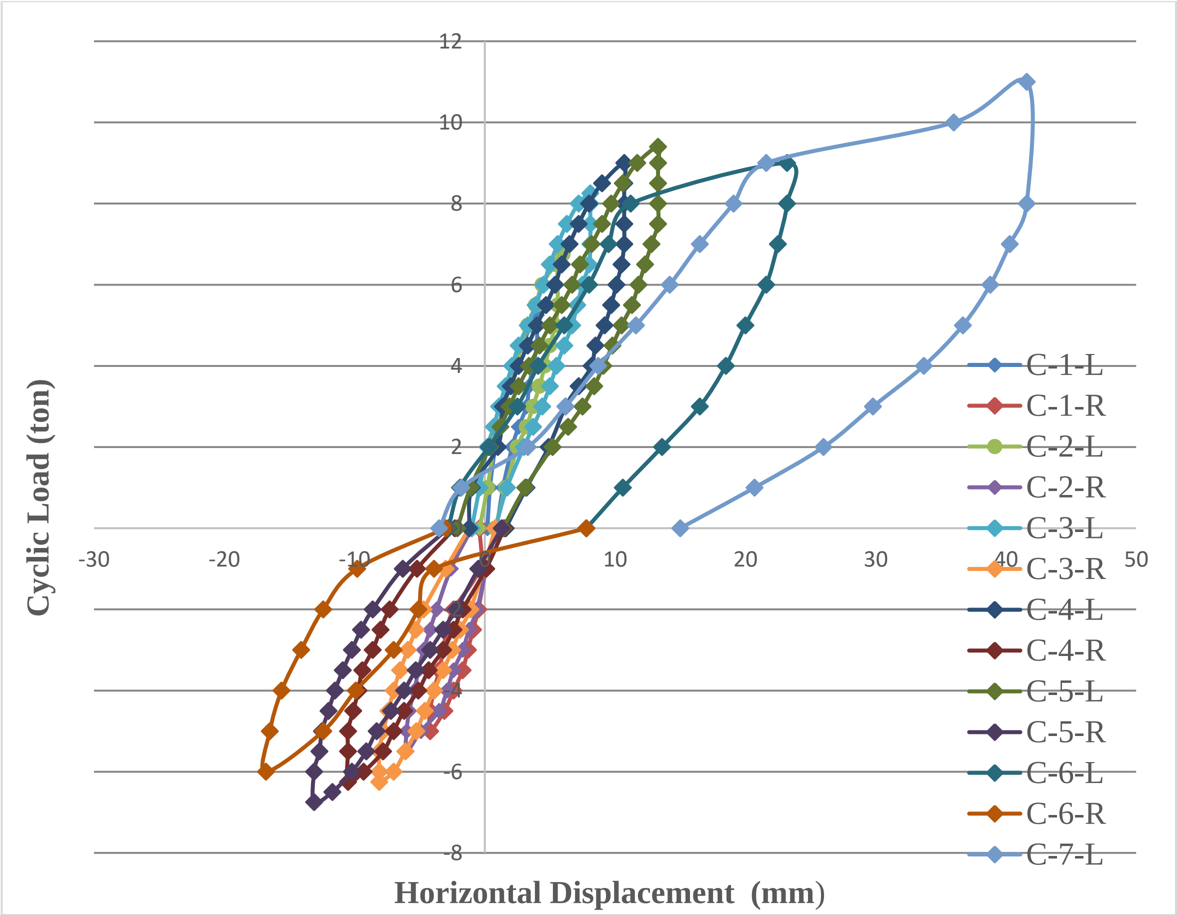


Figure 5.29: Load-Deformation Response of RS-1

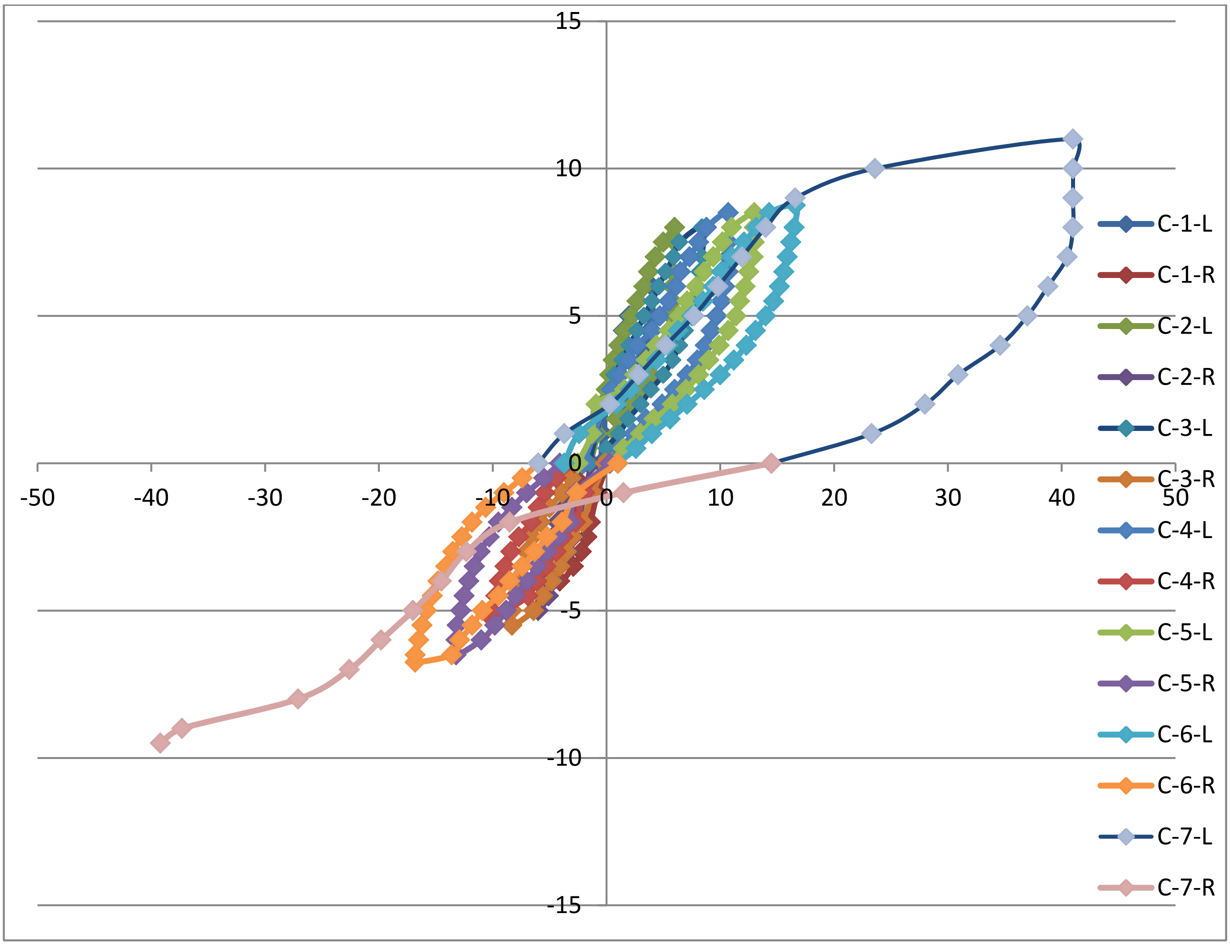


Figure 5.30: Load-Deformation Response of RS-2

Figure 5.31 to Figure 5.44 represent the load–displacement response of RSs at every different cycle independently.

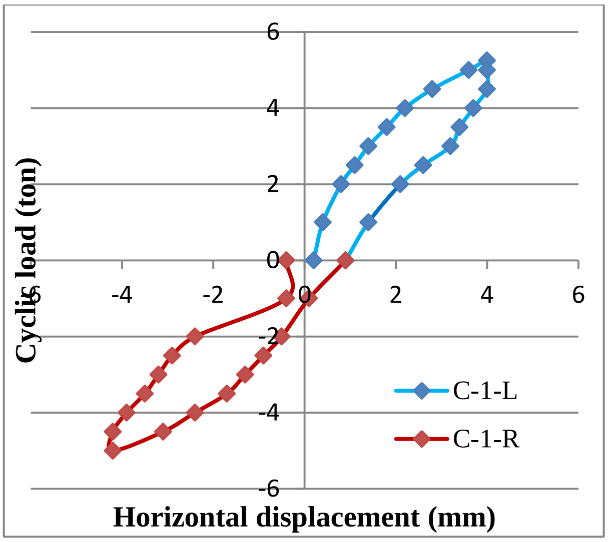


Figure 5.31: Cycle I for RS-1

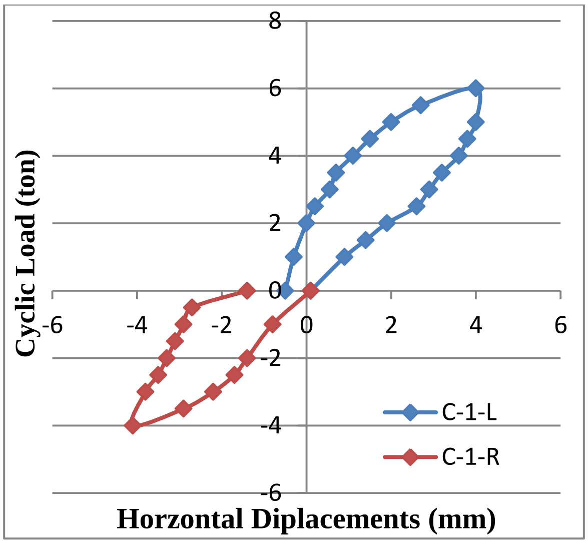


Figure 5.32: Cycle I for RS-2

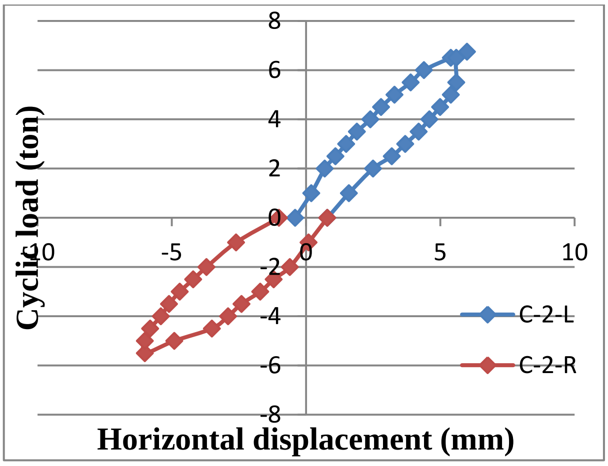


Figure 5.33: Cycle II for RS-1

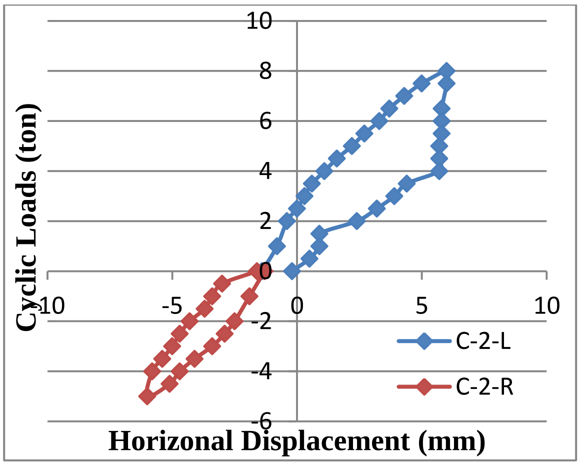


Figure 5.34: Cycle II for RS-2

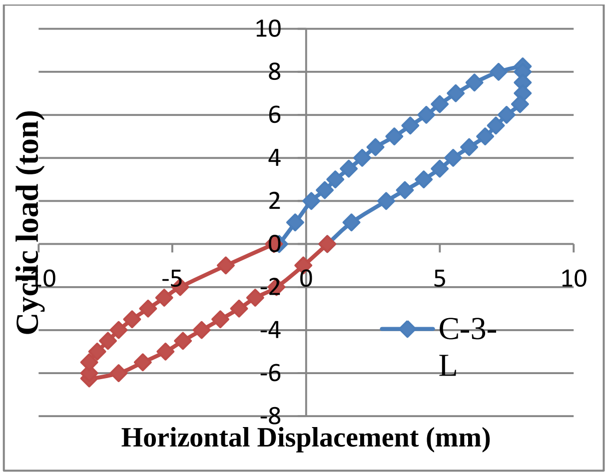


Figure 5.35: Cycle III for RS-1

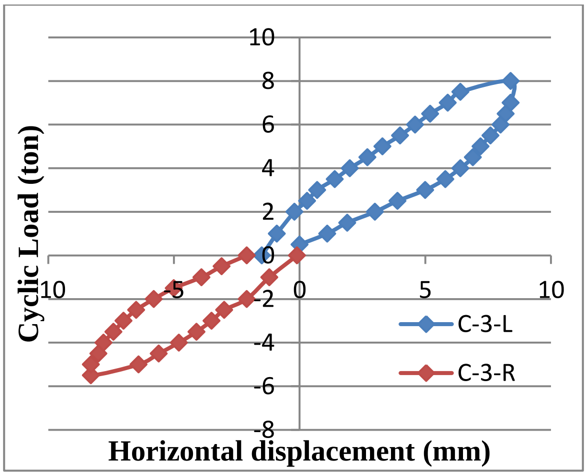


Figure 5.36: Cycle III for RS-2

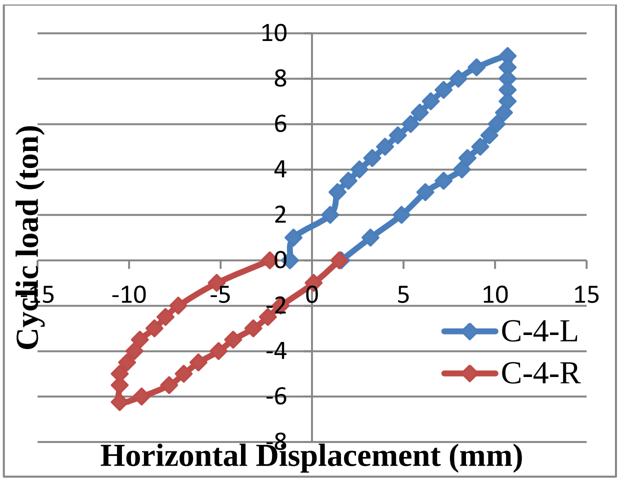


Figure 5.37: Cycle IV for RS-1

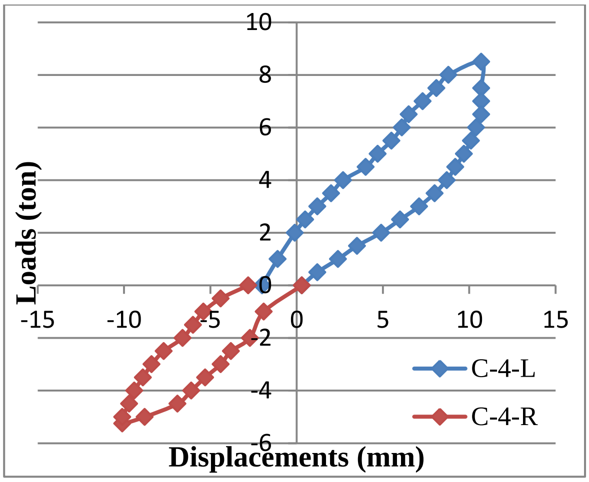


Figure 5.38: Cycle IV for RS-2

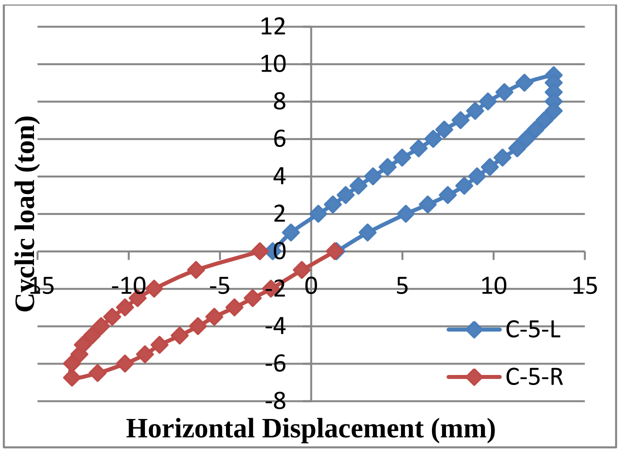


Figure 5.39: Cycle V for RS-1

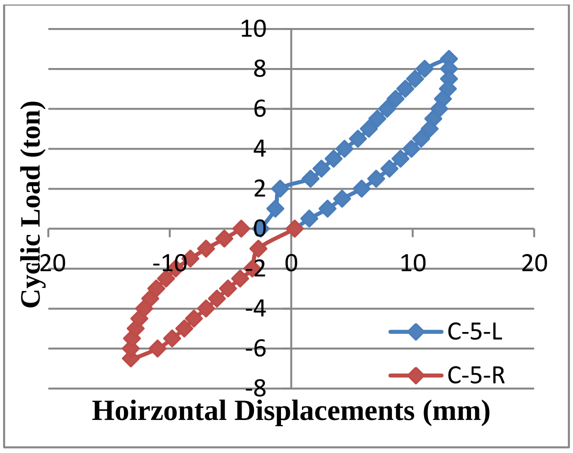


Figure 5.40: Cycle V for RS-2

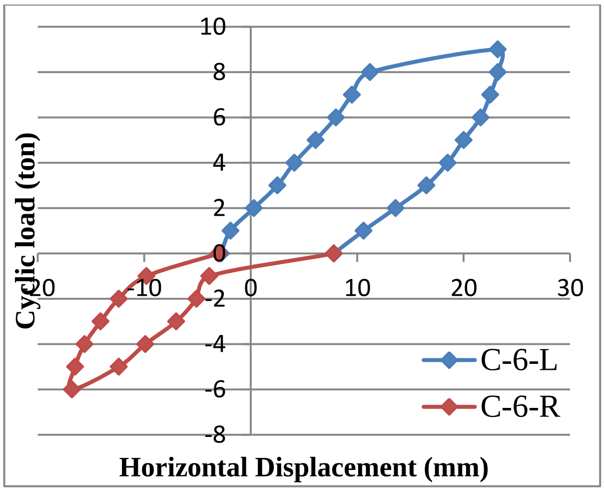


Figure 5.41: Cycle VI for RS-1

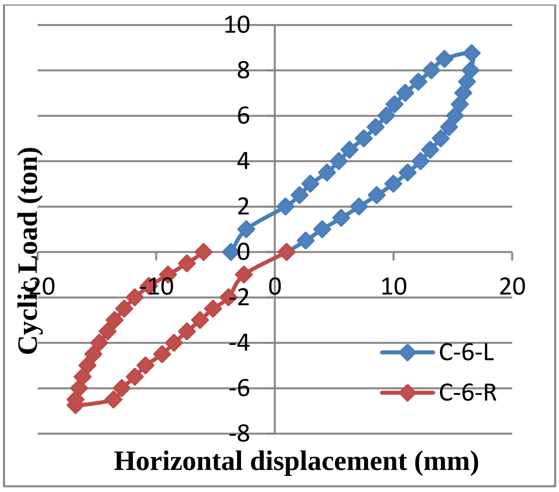
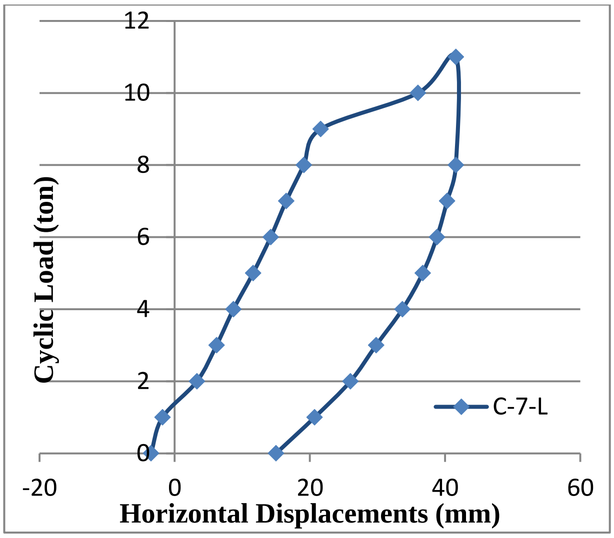


Figure 5.42: Cycle VI for RS-2



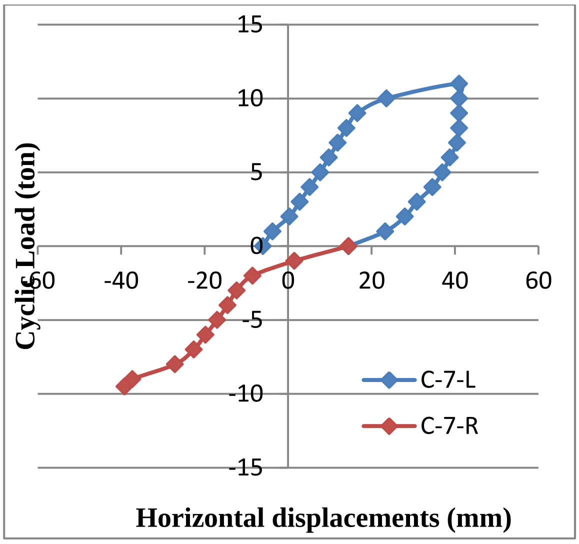


Figure 5.43: Cycle VI For RS-1

Figure 5.44: Cycle VI For RS-2

A summary of the results in terms of very first crack, first column crack and first beam crack at every specimen is shown in the table 5.2.

Table 5.2: Summary Result of Three Specimens

Phenomena	Specimen	Cycle	Horizontal Displacement (mm)	Lateral Load (ton)
Very first Crack	CS	Rightward 1st cycle (loading)	1.1	1
	RS-1	Rightward 1st cycle (loading)	1.1	4.5
	RS-2	Rightward 1st cycle (loading)	4	6
First column crack	CS	Rightward 1st cycle (loading)	1.1	1
	RS-1	Rightward 1st cycle (loading)	1.1	4.5
	RS-2	Rightward 2nd cycle (loading)	5	7.5
First beam crack	CS	Rightward 1st cycle (loading)	N/A	N/A
	RS-1	Leftward 4th cycle (loading)	1.1	4.5
	RS-2	Leftward 1st cycle (loading)	1.1	4

The very first crack for all specimens appeared in beam at the rightward loading of first cycle except for CS, for which first crack appear in the right column. The corresponding load of first crack appearance was different for the all specimens. And this was obvious because of difference in structural dimension of CS and RSs as well as strength.

The first column crack for all specimens appeared at the rightward loading of first cycle except for RS-2, for which first column crack appear at the rightward loading of 2nd cycle.

There was no crack in beam for CS. The First beam crack for RS-2 appeared at the leftward loading of 4th cycle. And for RS-2 the first beam crack appeared at the leftward loading 1st cycle.

With the purpose of investigating the magnitude of stiffness degradation, the slope of all loading-unloading curves after the completion of each full cycle was computed and it is shown in Table 5.3

Table 5.3: Stiffness of Three Specimens after Every Full Cycle

Cycle	Specimens	Stiffness after every full cycle	Remark on stiffness
Cycle I	CS	0.245 (for positive half cycle)	RS-1 is stiffer than other two.
	RS-1	1.25	
	RS-2	1.235	
Cycle II	RS-1	1.021	Stiffness is decreasing with increasing cycle. RS-2 is stiffer than other one.
	RS-2	1.083	
Cycle III	RS-1	0.895	Stiffness is decreasing with increasing cycle. RS-1 is stiffer than other one.
	RS-2	0.808	
Cycle IV	RS-1	0.719	Stiffness is decreasing with increasing cycle. RS-1 is stiffer than other one.
	RS-2	0.661	
Cycle V	RS-1	0.612	Stiffness is decreasing with increasing cycle. RS-1 is stiffer than other one.
	RS-2	0.573	
Cycle VI	RS-1	0.375	Stiffness is decreasing with increasing cycle. RS-1 is stiffer than other one.
	RS-2	0.464	
Cycle VII	RS-1	0.244	Stiffness is decreasing with increasing cycle. RS-1 is stiffer than other one.
	RS-2	0.234	

By comparing the slope value it was found that stiffness of all specimens was decreasing after every cycle. By comparing the stiffness of RSs, it was found that overall stiffness of RS-1 was higher than the RS-2. Figure 5.45 illustrated the slope.

Figure 5.45: Stiffness of the Specimens after Every Cycle

Table 5.4: Maximum Load with Corresponding Displacement for Every Cycle

Cycle	Specimens	Positive Maximum Displacement (mm)	Corresponding Load (ton)	Negative Maximum Displacement (mm)	Corresponding Load (ton)
Cycle I	CS	16.3	4	33.4	4
	RS-1	4	5.25	4.2	5
	RS-2	4	6	4.1	4
Cycle II	RS-1	6	6.75	6	5.5
	RS-2	6	8	6	5
Cycle III	RS-1	8.1	8.25	8.1	6.25
	RS-2	8.4	8	8.3	5.5
Cycle IV	RS-1	10.7	9	10.5	6.25

	RS-2	10.7	8.5	10.1	5.25
Cycle V	RS-1	13.3	9.4	13.1	6.75
	RS-2	13	8	13.2	6.5
Cycle VI	RS-1	23.2	9	16.8	6
	RS-2	16.6	8.75	16.8	6.75
Cycle VII	RS-1	41.6	11	N/A	N/A
	RS-2	41	11	39.2	9.5

Table 5.4 summarizes the maximum load recorded with the corresponding displacement for every cycle of all test specimens.

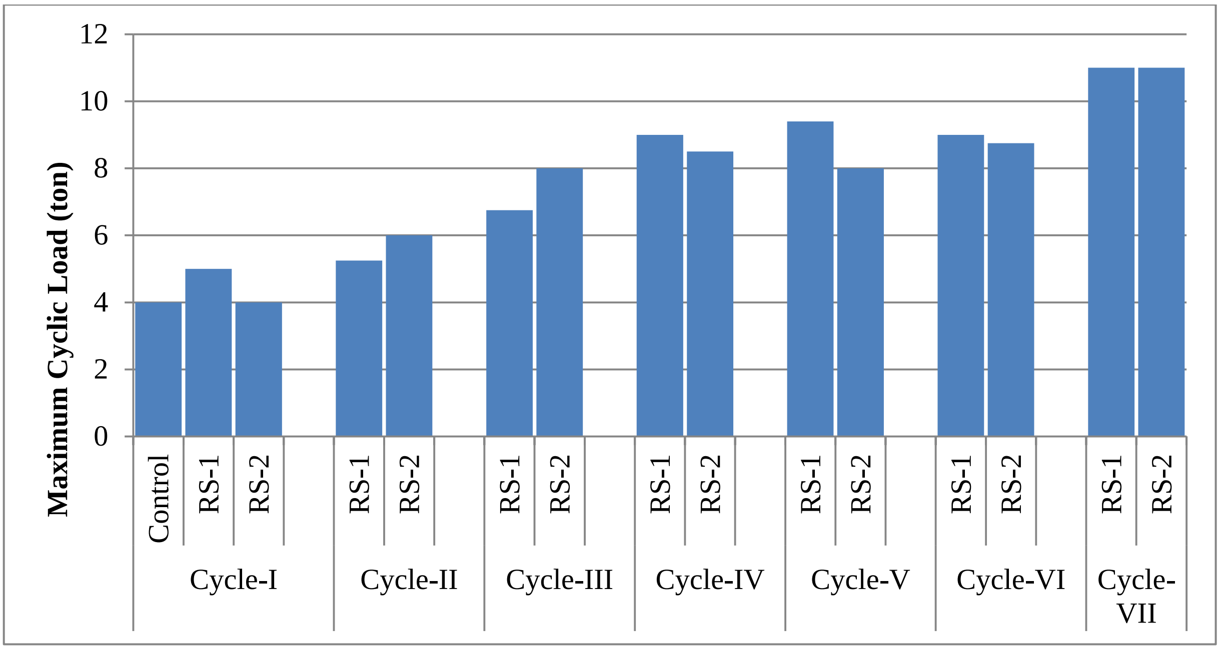


Figure 5.46: Maximum Displacement with Corresponding Load for Every Cycle

Table 5.5: Residue Displacement of Each Specimen after Test

Cycle	Specimens	Residual displacements after every full cycle (mm)
Cycle I	CS	+4.5 (for positive half cycle)
	RS-1	0.9 (for positive half cycle)
	RS-2	0.1 (for positive half cycle)

Cycle II	RS-1	-1
	RS-2	-1.6
Cycle III	RS-1	-1.2
	RS-2	-2.1
Cycle IV	RS-1	-2.3
	RS-2	-2.8
Cycle V	RS-1	-2.8
	RS-2	-4.1
Cycle VI	RS-1	-3
	RS-2	-6
Cycle VII	RS-1	+15 (for positive half cycle)
	RS-2	+14.5 (for positive half cycle)

Table 5.5 shows the comparison of residual lateral displacements for every cycle. As the CS failed before the completion first cycle, residual for CS was taken only for positive half cycle and for the purpose of comparison with CS, residual of RS was taken for positive half cycle. Comparing them, RS-2 had the less residual than the other two. For the rest of the complete cycles, it was observed that RS-2 had more residual displacements than the RS-1. This indicates the performance of RS-1 was better than the specimen-2.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

This research investigated the ultimate load carrying capacity and the maximum lateral displacement of RC columns strengthened by micro-concrete. All fabricated frame specimens were subjected to successive cyclic loading. Following conclusions are drawn based on the experiment and analysis of the results:

1. Ultimate lateral load carrying capacity of RS-1 and RS-2 was found to be 175% greater than that of CS.
2. Before formation of first crack, the RS-1 experienced 350% more lateral load than the corresponding CS whereas RS-2 experienced 300% more lateral load than CS.
3. Test results show that the CS suffered shear failure at the base of column and significant degradation of strength at relatively low lateral displacement.
4. Although RS-2 [8160 psi] was stronger than RS-1 [6300 psi], but it didn’t increase the load carrying capacity and the stiffness of the RSs significantly.
5. The failure mode of both RS-1 and RS-2 was anchorage failure. It indicates inadequate penetration of longitudinal rebars during retrofitting.
6. No hooks were provided in the longitudinal rebars during retrofitting of the columns. This resulted cracking in top of the column during the test.
7. The results of this investigation indicated that strengthening of a square reinforced concrete column with micro concrete may be considered as successful.

6.2 RECOMMENDATIONS FOR FURTHER STUDY

1. More frames should be tested to increase the accuracy of the results.
2. The longitudinal rebars which were used for retrofitting should be penetrated at least 150 mm into base beam.
3. Range of dial gauge should be at least 50 mm.
4. Vertical displacements should be measured during lateral loading and unloading.
5. Constant Uniformly Distributed Load may be imposed on the beam to observe the effect of it.

6. Other retrofitting materials (such as FRC, FRP etc.) should be used to observe the differences with micro-concrete.
7. The study discussed the comparison between two different strength of micro-concrete only. To know the performance of the normal concrete as a retrofitting material, specimens retrofitted with normal concrete should be tested.
8. Smooth surfaced formwork should be used.
9. A full scale model may be investigated to get more accurate result.
10. A comprehensive study should be made by involving both experimental and finite element analysis.

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APPENDIX

APPENDIX-A

Table A.1: Load Deflection Data for Control Specimen

CS	
Cycle I	
Deflection (mm)	Load (Ton)
0	0
1.1	1
3	2
6.5	3
16.3	4
16.2	3
13.1	2
8.4	1
4.5	0
4.2	0
1	-1
-4	-2
-12.5	-3
-33.4	-4

Table A.2: Load Deflection Data for Retrofitted Specimen-1

RS-1							
Cycle I		Cycle II		Cycle III		Cycle IV	
Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)
0.2	0	-0.4	0	-1	0	-1.2	0
0.4	1	0.2	1	-0.4	1	-1	1
0.8	2	0.7	2	0.2	2	1	2
1.1	2.5	1.1	2.5	0.7	2.5	1.4	3
1.4	3	1.5	3	1.1	3	2	3.5
1.8	3.5	1.9	3.5	1.6	3.5	2.6	4
2.2	4	2.4	4	2.1	4	3.3	4.5
2.8	4.5	2.8	4.5	2.6	4.5	4	5
3.6	5	3.3	5	3.3	5	4.7	5.5

4	5.25	3.9	5.5	3.9	5.5	5.4	6
4	5	4.4	6	4.5	6	5.9	6.5
4	4.5	5.4	6.5	5	6.5	6.5	7
3.7	4	6	6.75	5.6	7	7.2	7.5
3.4	3.5	5.6	6.5	6.3	7.5	8	8
3.2	3	5.6	5.5	7.2	8	9	8.5
2.6	2.5	5.4	5	8.1	8.25	10.7	9
2.1	2	5	4.5	8.1	8	10.7	8.5
1.4	1	4.6	4	8.1	7.5	10.7	8
0.9	0	4.2	3.5	8.1	7	10.7	7.5
0.1	-1	3.7	3	8	6.5	10.7	7
-0.5	-2	3.2	2.5	7.5	6	10.5	6.5
-0.9	-2.5	2.5	2	7.1	5.5	10.1	6
-1.3	-3	1.6	1	6.7	5	9.7	5.5
-1.7	-3.5	0.8	0	6.1	4.5	9.2	5
-2.4	-4	0.1	-1	5.5	4	8.5	4.5
-3.1	-4.5	-0.6	-2	5	3.5	8.2	4
-4.2	-5	-1.2	-2.5	4.4	3	7.2	3.5
-4.2	-4.5	-1.7	-3	3.7	2.5	6.2	3
-3.9	-4	-2.4	-3.5	3	2	4.9	2
-3.5	-3.5	-2.9	-4	1.7	1	3.2	1
-3.2	-3	-3.5	-4.5	0.8	0	1.6	0
-2.9	-2.5	-4.9	-5	0.8	0	1.5	0
-2.4	-2	-6	-5.5	-0.1	-1	0.1	-1
-0.4	-1	-6	-5	-1.1	-2	-1.7	-2
-0.4	0	-5.8	-4.5	-1.9	-2.5	-2.4	-2.5

		-5.4	-4	-2.5	-3	-3.2	-3
		-5.1	-3.5	-3.2	-3.5	-4.3	-3.5
		-4.7	-3	-3.9	-4	-5.1	-4
		-4.2	-2.5	-4.6	-4.5	-6.2	-4.5
		-3.7	-2	-5.25	-5	-7	-5
		-2.6	-1	-6.1	-5.5	-7.8	-5.5
		-1	0	-7	-6	-9.3	-6
				-8.1	-6.25	-10.5	-6.25
				-8.1	-6	-10.5	-5.5
				-8.1	-5.5	-10.5	-5
				-7.8	-5	-10.1	-4.5
				-7.4	-4.5	-9.7	-4
				-7	-4	-9.4	-3.5
				-6.5	-3.5	-8.6	-3
				-5.9	-3	-8	-2.5
				-5.3	-2.5	-7.3	-2
				-4.7	-2	-5.2	-1
				-3	-1	-2.3	0
				-1.2	0		

Cycle V		Cycle VI		Cycle VII	
Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)
-2.1	0	-2.8	0	-3.5	0
-1.1	1	-1.9	1	-1.8	1
0.4	2	0.3	2	3.3	2
1.2	2.5	2.5	3	6.2	3
1.9	3	4.1	4	8.7	4

2.6	3.5	6.1	5	11.6	5
3.4	4	8	6	14.2	6
4.2	4.5	9.5	7	16.5	7
5	5	11.2	8	19.1	8
5.9	5.5	23.2	9	21.6	9
6.7	6	23.2	8	36	10
7.3	6.5	22.5	7	41.6	11
8.2	7	21.6	6	41.6	8
9	7.5	20	5	40.3	7
9.7	8	18.5	4	38.8	6
10.6	8.5	16.5	3	36.7	5
11.7	9	13.6	2	33.7	4
13.3	9.4	10.6	1	29.8	3
13.3	9	7.8	0	26	2
13.3	8.5	7.8	0	20.7	1
13.3	8	-3.9	-1	15	0
13.3	7.5	-5.1	-2		
12.8	7	-7	-3		
12.3	6.5	-9.9	-4		
11.8	6	-12.4	-5		
11.3	5.5	-16.8	-6		
10.5	5	-16.5	-5		
9.8	4.5	-15.6	-4		
9.1	4	-14.1	-3		
8.4	3.5	-12.4	-2		

7.5	3	-9.8	-1		
6.4	2.5	-3	0		
5.2	2				
3.1	1				
1.4	0				
1.3	0				
-0.5	-1				
-2.2	-2				
-3.2	-2.5				
-4.2	-3				
-5.3	-3.5				
-6.2	-4				
-7.2	-4.5				
-8.3	-5				
-9.1	-5.5				
-10.2	-6				
-11.7	-6.5				
-13.1	-6.75				
-13.1	-6				
-12.7	-5.5				
-12.5	-5				
-12	-4.5				
-11.5	-4				
-10.9	-3.5				
-10.2	-3				

-9.5	-2.5				
-8.6	-2				
-6.3	-1				
-2.8	0				

Table A.3: Load Deflection Data for Retrofitted Specimen-2

RS-2							
Cycle I		Cycle II		Cycle III		Cycle IV	
Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)
-0.5	0	-1.4	0	-1.5	0	-2	0
-0.3	1	-0.8	1	-0.9	1	-1.1	1
0	2	-0.4	2	-0.2	2	-0.1	2
0.2	2.5	0	2.5	0.3	2.5	0.5	2.5
0.55	3	0.3	3	0.7	3	1.2	3
0.7	3.5	0.6	3.5	1.4	3.5	2	3.5
1.1	4	1.1	4	2	4	2.7	4
1.5	4.5	1.6	4.5	2.7	4.5	4	4.5
2	5	2.2	5	3.3	5	4.7	5
2.7	5.5	2.7	5.5	4	5.5	5.5	5.5
4	6	3.3	6	4.6	6	6.1	6
4	5	3.7	6.5	5.2	6.5	6.5	6.5
3.8	4.5	4.3	7	5.9	7	7.3	7
3.6	4	5	7.5	6.4	7.5	8.1	7.5
3.2	3.5	6	8	8.4	8	8.8	8
2.9	3	6	7.5	8.4	7	10.7	8.5
2.6	2.5	5.8	6.5	8.2	6.5	10.7	7.5

1.9	2	5.8	6	8	6	10.7	7
1.4	1.5	5.8	5.5	7.6	5.5	10.7	6.5
0.9	1	5.7	5	7.2	5	10.4	6
0.1	0	5.7	4.5	6.9	4.5	10.1	5.5
0.1	0	5.7	4	6.4	4	9.7	5
-0.8	-1	4.4	3.5	5.8	3.5	9.2	4.5
-1.4	-2	3.9	3	5	3	8.7	4
-1.7	-2.5	3.2	2.5	3.9	2.5	8	3.5
-2.2	-3	2.4	2	3	2	7.1	3
-2.9	-3.5	0.9	1.5	1.9	1.5	6	2.5
-4.1	-4	0.9	1	1.1	1	4.9	2
-3.8	-3	0.5	0.5	0	0.5	3.5	1.5
-3.5	-2.5	-0.2	0	-0.1	0	2.4	1
-3.3	-2	-1.3	0	-1.2	-1	1.2	0.5
-3.1	-1.5	-1.9	-1	-2.1	-2	0.3	0
-2.9	-1	-2.5	-2	-3	-2.5	0.3	0
-2.7	-0.5	-2.9	-2.5	-3.5	-3	-1.9	-1
-1.4	0	-3.4	-3	-4.1	-3.5	-2.7	-2
		-4.1	-3.5	-4.8	-4	-3.8	-2.5
		-4.7	-4	-5.6	-4.5	-4.4	-3
		-5.1	-4.5	-6.4	-5	-5.3	-3.5
		-6	-5	-8.3	-5.5	-6.1	-4
		-5.8	-4	-8.3	-5	-6.9	-4.5
		-5.4	-3.5	-8	-4.5	-8.8	-5
		-5	-3	-7.8	-4	-10.1	-5.25

		-4.7	-2.5	-7.4	-3.5	-10.1	-5
		-4.3	-2	-7	-3	-9.7	-4.5
		-3.7	-1.5	-6.5	-2.5	-9.4	-4
		-3.4	-1	-5.8	-2	-8.9	-3.5
		-3	-0.5	-5	-1.5	-8.4	-3
		-1.6	0	-3.9	-1	-7.7	-2.5
				-3.1	-0.5	-6.6	-2
				-2.1	0	-6	-1.5
						-5.4	-1
						-4.4	-0.5
						-2.8	0

Cycle V		Cycle VI		Cycle VII	
Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)	Deflection (mm)	Load (ton)
-2.5	0	-3.7	0	-6	0
-1.3	1	-2.4	1	-3.7	1
-0.9	2	0.9	2	0.3	2
1.6	2.5	2.1	2.5	2.8	3
2.5	3	3	3	5.2	4
3.5	3.5	4.4	3.5	7.7	5
4.4	4	5.4	4	9.8	6
5.5	4.5	6.3	4.5	11.9	7
6.4	5	7.5	5	14	8
7.1	5.5	8.5	5.5	16.6	9
7.9	6	9.4	6	23.6	10
8.6	6.5	10.1	6.5	41	11

9.4	7	11	7	41	10
10.2	7.5	12.1	7.5	41	9
11	8	13.2	8	41	8
13	8.5	14.3	8.5	40.5	7
13	8	16.6	8.75	38.8	6
13	7.5	16.5	8	37	5
12.9	7	16.2	7.5	34.6	4
12.5	6.5	15.9	7	30.9	3
12.2	6	15.6	6.5	28	2
11.7	5.5	15.2	6	23.3	1
11.4	5	14.7	5.5	14.5	0
10.7	4.5	14	5	14.5	0
9.9	4	13.1	4.5	1.5	-1
9	3.5	12.3	4	-8.5	-2
8.1	3	11.2	3.5	-12.3	-3
7	2.5	10	3	-14.5	-4
5.8	2	8.6	2.5	-17	-5
4.2	1.5	7.1	2	-19.8	-6
3	1	5.6	1.5	-22.6	-7
1.5	0.5	4	1	-27.1	-8
0.3	0	2.6	0.5	-37.3	-9
0.3	0	1	0	-39.2	-9.5
-2.7	-1	1	0		
-3.2	-2	-2.6	-1		
-4.2	-2.5	-3.9	-2		

-5.2	-3	-5.2	-2.5		
-6.1	-3.5	-6.3	-3		
-7	-4	-7.4	-3.5		
-8	-4.5	-8.5	-4		
-8.8	-5	-9.5	-4.5		
-9.8	-5.5	-10.9	-5		
-11	-6	-11.8	-5.5		
-13.2	-6.5	-12.9	-6		
-13.2	-6	-13.6	-6.5		
-13.1	-5.5	-16.8	-6.75		
-12.8	-5	-16.8	-6.5		
-12.5	-4.5	-16.5	-6		
-12.1	-4	-16.2	-5.5		
-11.6	-3.5	-15.8	-5		
-11.1	-3	-15.3	-4.5		
-10.3	-2.5	-14.8	-4		
-9.5	-2	-14.1	-3.5		
-8.3	-1.5	-13.5	-3		
-7	-1	-12.7	-2.5		
-5.5	-0.5	-11.8	-2		
-4.1	0	-10.6	-1.5		
		-9	-1		
		-7.4	-0.5		
		-6	0		

APPENDIX-B

CONPLAST SP430 G8

Health and Safety instructions

Conplast SP430 G8 is non-toxic. Any splashes on the skin should be washed immediately with water. Splashes on the eyes should be washed immediately with water and medical advice should be sought.

Description:

Conplast SP430 G8 is based on Sulphonated Naphthalene Polymers and supplied as a brown liquid instantly dispersible in water. Conplast SP430 G8 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability.

Advantages:

- Improved workability - Easier, quicker placing and compaction.
- Increased strength - Provides high early strength for precast concrete with the advantage of higher water reduction ability.
- Improved quality - Denser, close textured concrete with reduced porosity and hence more durable.
- Higher cohesion - Risk of segregation and bleeding minimized; thus aids pumping of concrete.
- Chloride free - Safe in pre-stressed concrete and with sulphate resisting cements and marine aggregates.

Standards compliance

Conplast SP430 G8 complies with IS: 9103:1999 and BS: 5075 Part 3. Conplast SP430 G8 conforms to ASTM-C-494 Type 'F' and Type 'A' depending on the dosages used.

Properties

Specific gravity 1.24 to 1.26

Chloride content Nil to IS: 456

Air entrainment Approx. 1% additional air is entrained

Compatibility: Can be used with all types of cements except high alumina cement. Conplast SP430 G8 is compatible with other types of Fosroc admixtures when added separately to the mix. Site trials should be carried out to optimize dosages.

Workability: Can be used to produce flowing concrete that requires no compaction. Some minor adjustments may be required to produce high workable mix without segregation.

Cohesion: Cohesion is improved due to dispersion of cement particles thus minimizing segregation and improving surface finish.

Compressive strength: Early strength is increased up to 20% if water reduction is taken advantage of. Generally, there is improvement in strength up to 20% depending upon W/C ratio and other mix parameters.

Durability: Reduction in W/C enables increase in density and impermeability thus enhancing durability of concrete.

APPLICATION INSTRUCTIONS

Dosage

The optimum dosage is best determined by site trials with the concrete mix which enables the effects of workability, strength gain or cement reduction to be measured. Site trials with Conplast SP430 G8 should always be compared with mix containing no admixture. As a guide, the rate of addition is generally in the range of 0.5 - 2.0 liters /100 kg cement.

Over dosing

An over dose of double the recommended amount of Conplast SP430 G8 will result in very high workability and some retardation of setting time will occur. However, the ultimate compressive strength will not be impaired.

Packing

Conplast SP430 G8 is supplied in 5, 20 and 200 liter drums.

Storage

Conplast SP430 G8 has a minimum shelf life of 12 months when stored under normal temperatures. It should be protected from extreme temperatures and preferably stored in shade.

CHEMICAL BINDER

Fosroc Lokfix 385

USES

High strength, corrosion resistant and heavy duty anchoring. These anchors include bolts, tendons or dowels in drilled or formed holes located in concrete masonry, brickwork or natural rock. Permanent installation of reinforcement starter bars, foundation bolts, balustrading, barriers and safety fences, railway tracks, ground anchors for towers, cranes, dock sills etc.

ADVANTAGES

- Ease of use
- Application system eliminates mixing and cleaning
- and reduces waste
- Can be used on horizontal and overhead applications
- High chemical resistance
- Long working time at elevated temperatures
- Flexible setting of bore diameter/annular gap
- Good performance in diamond drilled holes
- Very low shrinkage
- Performance tested by EMPA

DESCRIPTION

Two-part epoxy adhesive system for anchoring and dowelling reinforcement and threaded bars in solid concrete. The application system consists of a two-part cartridge with Handymax Gun and mixing wand tip. Epoxy is mixed at the required ratio in the gun tip and delivered directly into the drilled hole. This method gives uniform quality, reduced cleaning and reduced material wastage. The epoxy mortar has provides very high compressive and tensile strength giving bond strengths in excess of reinforcement tensile capacity.

DESIGN CRITERIA

Fosroc Lokfix 385 has been independently tested by EMPA, the Switzerland materials science and technology research institution. When used to bond high tensile deformed reinforcement into solid concrete with an embedment depth of 16 times bar diameter the bond strength is normally in excess of tensile yield point of reinforcement bar Fosroc Lokfix has a very high bond strength with both hammer and diamond drilled holes. When reinforcement bar are anchored close to the slab edge or close proximity to each other, modification factors are required to compensate for these factors. Please consult your local Fosroc technical department with your required design arrangement.

Table 1 –Epoxy Mortar Physical Properties

Compressive strength at 7 days	140 N/mm 2
Elastic modulus at 7 days	7,300 N/mm 2
Tensile bending strength at 7 days	60 N/mm 2
Shrinkage ratio 0	.003
Gel time (@ 30 O C)	20 minutes
Initial cure (@30OC)	5 hours

TABLE 2 –BOND STRENGTH

Characteristic concrete strength (f_{cu}) 45 N/mm 2					
Bar dia. mm	Hole dia.[1] mm	Bond length mm	Failure load KN	Bond strength N/mm	Failure mode (1)
12	15	180	186	8.21	DF
16	20	250	229	9.06	DF
20	25	350	299	8.46	DF/SF
26	33	400	350	9.37	SF

(1) Failure modes:

DF Ductile Failure of rebar

SF Shear Failure of concrete around the rebar

APPLICATION INSTRUCTIONS

Hole preparation and formation

Three methods of hole formation are possible.

- Optimum performance of adhesive anchor requires rough sided, dust free holes. These can be made by using rotary percussive drills followed by oil-free air or water flushing.
- Diamond drilled holes should be under-reamed.
- Cast holes should be of inverse dovetail configuration. If parallel sided holes are cast, they should be rough enough to provide an adequate mechanical key.
- All holes must be cleaned using nylon or wire brush followed by blowing out hole using clean/filtered compressed air.

BAR PREPARATION

All bars should be deformed. This will ensure good bond between the bar and the grout. Bars should be degreased and any mill scale or flaky rust removed.

APPLICATION

Insert cartridge into Handymax Gun and screw on static mixer tip Discard first 3 trigger pulls of material Inject material into the hole starting at the bottom until required volume of mortar has been placed inside the hole. Volume can be measured based on the number of trigger pulls Insert rebar or threaded rod into hole, twisting during installation. A small amount of mortar should be visible at the hole entrance as the bar is pushed in. Rebar or fastener may be adjusted during specified gel Do not disturb rebar between specified gel time and initial cure. After initial cure work may proceed which will not exceed 25% of full working load? After full cure full load/torque may be applied to the rebar/threaded rod.

ESTIMATING

Supply

Fosroc Lokfix 385 385 ml cartridges and Handy max Gun Piece

COVERAGE

Table 3: Volume of mortar required in ml for each 100 mm of bond length

Hole dia. (mm)	Bar dia. (mm)				
	12	16	20	25	32
15	7	N/A	N/A	N/A	N/A
20	25	15	N/A	N/A	N/A
25	40	30	20	N/A	N/A
32	75	65	55	25	N/A
40	N/A	N/A	N/A	85	50

PRECAUTIONS

Health and safety Lokfix 385 is non-flammable. In the event of fire extinguish with water some people are sensitive to resins and solvents. Avoid contact with skin and eyes. Ensure adequate ventilation and avoid inhalation of vapors. Wear suitable protective clothing, gloves and eye/face protection. Barrier creams provide additional skin protection. Should accidental skin contact occur, wash immediately with a resin removing cream, followed by soap and water. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice -do not induce vomiting. For additional information see the relevant Material Safety